ON DISTURBANCES OF THE LOCALIZATION AND DISCRIMINATION OF SENSATIONS IN CASES OF CEREBRAL LESIONS, AND ON THE POSSIBILITY OF RECOVERY OF THESE FUNCTIONS AFTER A PROCESS OF TRAINING.

(I) PARTIAL RECOVERY OF THE ACCURACY OF LOCALIZING TACTILE STIMULI, TOGETHER WITH A DISCUSSION OF THE FACTORS WHICH UNDERLIE THE PROCESS.

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CONTENTS.

I.—Introduction.

It has been known for some time that recovery of function may take place after a lesion of the so-called "motor" area of the cerebral cortex in the higher mammals—although for a time after the infliction of the lesion there occurs paralysis of "voluntary" motion of the parts of the opposite side of the body which were served by the area destroyed.

The possibility that recovery of function may take place in a similar way after a destructive lesion of the so-called "sensory" area of the cerebral cortex is a question which has hitherto received little attention.

Such an investigation would be difficult (although perhaps not impossible) to perform in animals. It is obviously more easy to make in the case of man, but suitable cases are rarely encountered in civil practice. At the present time, however, much material for its prosecution is being provided by gunshot wounds of the cerebrum. Although we have had access to but few organic cerebral cases, of late we have been fortunate enough to have two such cases under our observation.

Although little or nothing is known of the manner of working of the mechanism in the cortex cerebri, it seems probable at any rate that the paths by which the impulses which subserve sensations are carried to the cortex are more complex than those which carry the so-called "motor" impulses for "voluntary" action away from it.

Head and his co-workers have shown that probably the afferent impulses which subserve the different forms of sensation conditioned by stimulation of end-organs in the skin and deeper structures are re-arranged in the spinal cord at or near the level of entry of the nerve-fibres which carry them. A second re-arrangement takes place at the level of the nuclei of the posterior columns of the cord in the medulla oblongata, while a third re-arrangement occurs at the optic thalamus.

In the spinal cord the afferent impulses which subserve the sensations of pain, of heat and of cold cross to the opposite side of that organ soon after their entry and then are carried upwards in secondary nerve-paths upon the side opposite to that from which they entered. The afferent impulses which subserve postural recognition and spatial discrimination run upwards upon the same side of the spinal cord as that of their entry. They travel along primary nerve-fibres in the posterior columns of the cord. The afferent impulses which subserve contact sensibility seem to travel upwards in a double path—partly on the same side and partly on the opposite side of the spinal cord to the side of entry. These impulses are evoked by touch and by pressure; this group carries with it the impulses which underlie the power of recognizing the situation of the stimulated spot.

At or above the level of the nuclei of the posterior columns of the cord the paths which carry the afferent impulses which subserve the sensations of pain, heat and cold run unaltered upon the opposite side of the brain stem to the optic thalamus; save only that there appears to be a certain degree of independence between the paths for the impulses

associated with these three sensations. The primary nerve-fibres which carry the impulses for postural recognition and spatial discrimination end in the nuclei of the posterior columns. Thence these impulses are carried upwards to the optic thalamus in two independent secondary paths—one for the impulses which subserve postural recognition and one for those which subserve spatial discrimination. The other uncrossed afferent paths now cross over to the side of the central nervous system opposite to that on which they entered.

According to the views of Head and Holmes [1], these various afferent paths—all now secondary—end in the optic thalamus where yet another redistribution takes place. From an examination of clinical material these observers believe that in the optic thalamus there is, besides the group or groups of nerve-cells at which all the afferent secondary nerve-fibres end, a mass of greymatter which they term the "essential organ of the optic thalamus." This, they suppose, forms the centre for certain fundamental elements of sensation. Its activity is mainly occupied with the affective side of sensation, and it is the "centre of consciousness" for certain elements of sensation—responding to all stimuli which are capable of evoking either pleasure and discomfort or consciousness of an internal change in state. The afferent impulses which subserve these sensations are presumably carried in short tertiary nerve-fibres from the nerve-cells at which the secondary nerve-fibres end to those in the essential organ of the thalamus.

Besides these short intra-thalamic tertiary nerve-paths there are, they suppose, longer tertiary nerve-fibres which carry on other afferent impulses from the nerve-cells at which all the secondary afferent fibres end in the thalamus to the cortex cerebri. These afferent impulses have been re-arranged in the optic thalamus and now run in five distinct paths—that is, in five paths, any one of which may be affected separately by a cerebral lesion. These five groups are: (1) the afferent impulses concerned with the recognition of posture and passive movement, and subserving the secondary faculty of discriminating weights on the unsupported hand; (2) those which subserve certain tactile elements (and also the discrimination of weights on the supported hand); (3) those which subserve spatial discrimination (the appreciation of two points applied simultaneously to two different points on the surface of the skin, and also the recognition of the size and shape of objects which are in contact with the skin); (4) those which subserve the power of localizing the situation of a stimulated spot of the skin, and that of the recognition of the double nature of two points applied

consecutively to too different spots on the skin; (5) those which subserve a scale of sensations with heat at the one end and cold at the other.

These observers believe that out of such materials the cortex cerebri fabricates the sensations for which it is responsible. They think that a great function of the cortex is the power of relating one sensation with another.

Now, if an object from the outside world comes into contact with a flat area of the skin the resultant stimuli engender afferent impulses which ascend in the central nervous system and finally subserve sensations of different kinds. These may be interpreted in consciousness in different manners. The relative hotness or coldness of the object, its roughness or smoothness, its size and shape, its weight and the part of the skin with which it is in contact, may all thus be perceived if we take a specific area of the skin, and apply tactile stimuli to spots within it; these stimuli may finally give rise to sensations which give information with regard to the locality of the touched spot within that area, or with regard to the doubleness of the touches if two different spots are touched either simultaneously or successively, and so on.

After certain cortical lesions the interpretation of these sensations may be greatly interfered with, and the description by the patient of the sensation (for instance, with regard to the localization upon the skin of a spot which has been touched) may be confused and wrong, or he may not be able to describe it at all.

The interesting question arises, whether in such a case it is possible to "educate" or "train"[1] the patient in such a manner that his replies to questions of this nature become accurate. Head and Holmes state that even twenty-three years after certain cortical lesions there may still be complete loss of the power of discrimination of two different points upon the affected side (compass-test), grave disturbance of the power of localization of tactile stimuli, and abolition of the power of appreciation of size, shape, and form in three dimensions, and of the power of recognition of familiar objects.

As far as we know, no attempt has hitherto been made in such a case to "re-educate" the lost faculties. The patient can hardly be expected to do this himself unless definitely directed to do so. For all practical

[1] We prefer the word "training" to signify a process by means of which such a lost cortical (or cerebral) function as that of localization might possibly become restituted. This word appears to us to have a more neutral meaning than "education" or "re-education," and to avoid committal to any theory with regard to a change which may possibly take place.

purposes his recognition of these attributes of objects is easier performed by sight (and, of course, by the unaffected hand), and there is little or no necessity for the "training" of recognition through the persisting sensations from the affected limb.

But if a definite effort is made is this "training" possible? If it is certain further questions of interest are raised. What are the factors which condition the appearance of improvement? Is it permanent or transient? Is it partial or complete? Again, suppose that it is possible to "re-educate" a lost faculty of the localization of tactile stimuli for certain definite spots on the skin, does the "re-education" affect the relative accuracy of the localization of tactile stimuli for other (let us say, neighbouring) spots which have not directly been "re-educated" for this faculty? Does a possible betterment of the localization of tactile stimuli for these specific spots which have been directly trained affect the accuracy of localization for other kinds of stimuli (that is, heat, cold, pain, &c., as well as other degrees of tactile stimuli than that used in the "re-education") for the same specific spots? And are other forms of sensation affected?

These problems are investigated in the experiment described in this paper. Before we attack them certain points in connection with the localization of cutaneous sensations may be considered.

II.—On Discrimination and Localization of Tactile Sensations.

When the normal subject of an experiment is so placed that he is unable to see a specific area of his skin—for instance, that of the palmar aspect of a finger—and a supra-liminal touch stimulus is then applied to a spot within it, he is able at once accurately to point to the corresponding spot on the hand of a model, although the only peripheral data which he receives are those of the touch stimulus itself.

The stimulus sets into action certain receptive end-organs in the spot of skin and underlying tissues. Thence afferent impulses pass into and up through the central nervous system until (probably) they effect activities in the cortex cerebri. There a complex physiological process occurs, the final resultant of which is the activation of certain "motor" mechanisms which in the end condition a very accurate movement of the hand which indicates the corresponding position of the touched spot upon the model. Parallel with the cortical changes there are changes in consciousness. The sensation conditioned by the stimulus is perceived; and, with it, various attributes of which the locus of the stimulus upon the surface of the body is one.

In the conditioning of the accuracy of this localization of the touched spot we may discern three factors.

In the first place, the sensations conditioned by the tactile stimulus must in some manner be different from those conditioned by all other tactile stimuli which are applied to other spots of the skin. This attribute of the sensation conditioned by tactile stimulus may be termed (for convenience here) its "character." It is clear that, if there was no such difference between the sensations which are conditioned by, or accompany, differently located tactile stimuli, accurate localization of any one of them would not be possible.

In the second place, the sensations conditioned by the tactile stimulus must in some manner be like those conditioned by all previous tactile stimuli which have been applied in the past to the spot which is now touched; and, moreover, it must also be like the sensations conditioned by other previous stimuli, such as those of pain, heat, or cold—for if one of these is applied to this spot it is also accurately localized there. This attribute of the sensations conditioned by the stimulus may be termed its "individuality." It is clear that if the sensations conditioned by different tactile stimuli which are applied at different times to the same spot have not a common "individuality" accurate localization of any one of them would not be possible, and the subject at one time might localize the stimulus in one place, and at another time in another place.[1]

These attributes of the sensation conditioned by a tactile stimulus are not, however, in themselves sufficient for the exact localization of a touch. The character of the touch may serve to distinguish it from all other touches which are applied to other spots, and its individuality may serve to liken it to all previous touches which have fallen on the same spot. The resultant localization might still be impossible or, although a constant one, it might be inaccurate. That is to say that the subject might localize a touch which is applied to a certain spot on the palmar surface of one of the fingers of his right hand at a dissimilar spot on the palm of the model, thinking that that spot corresponded in

[1] In this paper we use the term "location of the stimulus" to express the act of the observer in applying the stimulus to a certain spot on the body of the subject; or to express the locus of that stimulus as it appears to the observer. We use, on the other hand, the term "localization of the stimulus" (or "of the spot," or "of the sensation conditioned by the stimulus"—indifferently) to express the cerebral process whereby the subject finally indicates the position which he thinks that the touched spot occupies. We do not go into the question whether the subject localizes the stimulus, or the sensation conditioned by it, but use the two forms of expression indifferently.

position to the spot on his own finger which was touched. Each time that spot is touched on his own finger he may locate the touch on that one dissimilar spot on the palm of the model. In such a case the localization of the tactile stimulus would be constant, but it would be inaccurate.

A third attribute of the touch must therefore be its topographical position upon the surface of the body. This we may term its factor of "position."

These three hypothetical attributes of the touch—its character, its individuality, and its position—are not mere refinements of analysis. Their consideration has a very direct bearing upon the problem of errors of localization and of discrimination of tactile stimuli.

The effect of a certain lesion of the cortex cerebri may be to destroy the faculty of localization of a touch. That touch may still be perceived in consciousness as such, but the patient may be unable to refer it (or to refer it accurately) to the corresponding spot on the model (that is, to the "similar" spot on the model) if he is unable to see the spot which has been touched.

Now in such a case the subject may be unable to localize the touch at all. As in many of the cases cited by Head and Holmes, he may be "confused" when he is asked to point to the corresponding spot on the body of the model. He is completely ignorant of its location. There is no question here of the character, individuality, or position of the touch; the subject is, as it were, "cortically blind" to localization—just as "cortical blindness" is associated with certain lesions of the cerebrum.

But the subject (in other cases) might still think that he is able to localize the touch. In such a case he may make the attempt to localize it; but each time he is wrong in his localization. Touches which are applied at different times to one and the same spot of the subject's skin may be localized by him at different spots on the model; and different touches on the subject may, at different times, be localized upon the the same spot on the model. In such a case the faculty of localization may be said to be "impaired" or to be "abolished" for certain areas of the skin—but it is evident that the condition is a different one from that in which the subject is unable to make any attempt at localization of the stimuli. That is, of course, if it is certain that the subject is not merely guessing the positions of the stimuli.

In a case in which the subject thinks that he can localize his tactile stimuli the ordinary methods of examination yield results of little value for the analysis of his condition. It is not sufficient for the observer to

touch one of an infinite number of spots on the subject's hand, and to note simply that the spot is wrongly localized upon the model. Information is needed with regard to the wrongness of the answers. It is needed for data with regard to the question whether a touch which is applied to a certain specific spot is always referred to the same (wrong) position on the model; and whether that same position on the model is sometimes indicated as the corresponding location of touches which are applied to other spots on the subject.

In an ordinary test of the function of localization of touches the area investigated is usually restricted. That is to say, that the subject usually knows that the stimulus will be applied to a spot on a certain restricted area of the skin—for instance, to the skin of the hand, or to that of the arm, and so on. If a further restriction is made, and the subject is allowed to know that the stimulus will be applied to one of a definite small number of spots upon (let us say) his hand, the conditions of the experiment are such that information with regard to the manner of the wrongness of localization of touches may be obtainable.

Now, if the character of the sensations conditioned by tactile stimuli applied to our chosen spots is lost, the subject may refer the locus of a stimulus which falls upon one of them to a certain spot on the hand of the model. It is theoretically possible that he may think that he has made an accurate localization of it; but when a certain other spot is touched he may also refer the locus of that touch to the same spot on the model, and still think that the localization is accurate. In other words, he may think that the two different tactile stimuli are applied to the same spot, whereas, in fact, they are applied to different spots. If the character of the touches is lost for spots in a certain area of the skin it might be thought that the attributes of individuality and posture would be lost at the same time. This is, perhaps, not necessarily the case. Thus the touches applied to spots in that area might lose their attribute of character—so that they would seem all to have the same locus. The touches become similar, and at the same time the attribute of individuality of the different touches would merge in a common individuality. This is not the same as a loss of the attribute of individuality; we might say, perhaps, that difference of individuality is a function of the characters of sensations conditioned by differently located tactile stimuli. When the attribute of character is lost the attribute of individuality may become a common one for sensations conditioned by tactile stimuli applied to the spots in this area. In a similar manner, the attribute of position might possibly also persist

even after the loss of the attribute of character. Thus the differences of individuality of the sensations conditioned by tactile stimuli which are applied to spots in a certain area of the skin having been merged in a common individuality, the subject may still think that he can localize the touches. Here he has, as it were, a number of possible places upon which he can localize the touches which seem to him to be similar. One of these may be chosen (perhaps, by "chance"), but thereafter he would be expected to continue to localize all these touches on this one spot of the hand of the model—at any rate, during the course of one series of readings.

In such a case the first localization of a touch which is applied to the affected area may be a matter of chance. Thereafter, all other touches applied to different spots in this area will be referred to the same spot on the model. But if a limited number of spots are taken for examination in the affected area of skin; and if these spots are marked upon the hand of the model; and if the patient knows that the touches of which he is conscious must be localized upon one of these spots on the model or not at all; when the different spots on the patient are touched in an irregular order the patient will either localize the touches all on one of the spots on the model—or will indicate here and there that he is unable to localize a touch. If failures to localize are disregarded, the answers will tend to run in long similar series and (provided each of the spots on the patient is touched the same number of times in the series) the average error will be the same as that of hazard—it will be the same, that is, as if the answers were chosen by lot. The following example from actual experiment is similar to what might be expected to be obtained. Three spots only are examined. The numbers on the upper line are those attached to them; those on the lower line are the numbers of the corresponding spots on the model which were indicated by the patient as corresponding to the location of the touches. The interruptions in the series were not present in the experiment and are here interpolated in order to indicate the series of similar numbers in the answers:—

232	1	3231	3	1	2	3	2112313211	3232313	213212	132312	1
333	1	2222	3	1	2	3	2222222222	3333333	222222	111111	2

Had the answers in the above experiment been determined solely by chance, or had the same answer been given throughout the whole series, the number of wrong answers would have been 28—a percentage error of 66·7. Actually it is 23—a percentage error of 54·8.

In the example given above, it will be observed that, although the answers tend to run in series of similar localizations of dissimilar touches, the same answer is not given constantly. Often, but not always, the first answer in a series is a correct one, and for a time thereafter all the touches are localized on the same spot of the model. It may be that in such a case the attribute of character of the tactile stimuli is not entirely abolished, but is impaired; or it may be that the attribute of individuality is impaired, while the attribute of character is abolished. It is probable that the attribute of individuality attached to tactile stimuli has an element of "memory" in it. If this is defective, it might happen that although the characters of the spots in the affected area of skin are abolished, and the touches which are applied to them seem to the subject to be similar, yet the apparent individuality of the merged character might vary from time to time in the experiment. All the different touches then might at one time be thought by the subject to have the individuality of one of them, and they might be referred by him to the locus of that stimulus; whilst at another time these same different touches might be thought by him to have the individuality of another of them, and would be localized on another position.

If the attribute of individuality is not merely impaired, but is actually abolished along with the destruction of the attribute of character, and if yet the attribute of posture remains, the touches would appear to the subject to be similar, and he would think that he could localize the apparently common touch; but he would be expected to localize it, now here and now there, in the different possible positions. In such a case the error in localization would still be that of hazard; but the answers would no longer tend to run in long similar series.

The following example from actual experiment (in which the test was one of recognition of three different two-dimensional shapes applied to the palm of the hand) is similar to the records which might be expected to be obtained:

3123231812123121232132132313213212313123123321233212232132123212312312321233132232

Here, out of 42 instances, in which three different stimuli are given each 14 times, 28 wrong answers are given. This gives a percentage error of 66·7 — exactly that which would be expected to be given if the answers had been selected by hazard. But on only five occasions is the same answer given twice consecutively.

Therefore it may be said that if the attribute of character of

touches is lost, but the attributes of individuality and position remain unimpaired, it would be expected that the localization of the different touches would be wrong (the average error being that of hazard); but the different touches would tend to be localized all on the same spot. If, however, the attribute of individuality is lost or impaired along with that of character, it would be expected that the error of localization would be the same as before (that is, the error of hazard), but there would be a tendency to indiscriminate variation in the position to which the touches are referred. If the attribute of position is lost, the patient would be expected to be confused, and unable to localize the stimuli at all.

It is possible to suppose that the attribute of character may be unimpaired, while that of the individuality of the touches is abolished. In such a case one touch will appear to the subject to be different from another, but a touch will not appear to be the same each time it is applied to a certain spot. Therefore if a number of tactile stimuli are applied in an indifferent order to a restricted number of spots on the affected area of the skin, the subject of the experiment will rarely confuse two different successive touches, but he will refer a stimulus which at different times is applied to one and the same spot, now to one of the possible positions, now to another, and only occasionally to the right one. In other words, where the tactile stimuli are not applied twice in succession to the same spot the answers will not tend to run in long similar series; but they will, nevertheless, tend to be wrong, and the average error will be that of hazard. The following example from actual experiment is similar to what might be expected to be obtained in these circumstances :—

2312312313218121312323123231312123121232183212312312331291313132181231913233232131321

Here the number of wrong answers is 23 out of a possible number 42—a percentage error of 54·8. The question "3" is put 14 times, and is given right on 5 occasions and wrong on 9—a percentage error of 64·3. Of the wrong answers "1" is given 5 times, and "2" is given 4 times; so that the percentages of the possible answers — "1" and "2" (wrong) and "3" (right) — are 35·7, 28·6, and 35·7: that is, as near as is possible with a small number of observations to the proportions of hazard. In the case of "1" and "2" in this experiment, this close approximation does not occur.

If the attribute of position of the touches is lost along with that of individuality, the subject would be expected to be unable to make an

attempt at localization, although he might still be able to recognize that there was a difference between touches which were applied to different spots on the affected area.

Finally, if the attribute of position is alone abolished, it is theoretically possible that the subject may be able to recognize differently located touches as in some way different, and a touch as in some way similar to previous touches of the same spot, and yet would still be unable to make a localization of these touches.

We may restate the above paragraphs by saying that for the proper localization of a touch we must probably assume that the sensation conditioned by the stimulus has three attributes apart from its quality. These are—its character, its individuality, and its position. By restricting the number of spots touched in a test, and the number of possible replies of the subject, we have a means of distinguishing between them. If the attribute of position is destroyed the subject should (theoretically) be unable to make a localization, and the error may be termed one of 100 per cent. If the attribute of character is alone destroyed the subject should tend to locate touches which are applied to different spots upon a single spot, so that the answers to series of tactile stimuli, no consecutive two of which are applied to the same spot, should run in series of identical replies. The percentage error should be that of hazard. If the attribute of individuality is alone destroyed the subject should tend to distinguish between consecutive dissimilar touches, but should tend to localize any one individual touch indifferently on any of the possible positions. The percentage error should still be that of hazard, but the answers to a series of dissimilar tactile stimuli, no consecutive two of which are the same, should run in series of which also no consecutive two are similar. If a series of tactile stimuli are applied to the same spot the answers should vary.

It must be noted that, on theoretical grounds, abolition of the attribute of character along with that of individuality should give the same results in the answers to a series of tactile stimuli, no consecutive two of which are the same, as abolition merely of the attribute of individuality. Is it possible to separate these two hypothetical conditions by test?

The investigation of the effects of touching two different spots either synchronously or consecutively with the compasses may possibly give such a test. If the attribute of character is abolished, when the points of the compass are applied simultaneously to two different spots the resultant sensation should, theoretically, be one of singleness. And

singleness should also result when a very short interval of time separates the application of the first point of the compass from that of the second. These effects should also, theoretically, be obtained when the attribute of individuality is lost as well as that of character. If the attribute of individuality alone is lost the simultaneous application of the two compass points should theoretically give a feeling of doubleness, as should also the asynchronous application of the points to two different spots. Thus, on purely theoretical grounds, it is to be supposed that where the attribute of individuality alone is lost the compass tests will differ from those obtained when the attributes of character and individuality are both lost. In the former case there will be no failure to recognize the doubleness of two touches when the compass points are applied either synchronously or successively to two different spots in the affected area; while in the latter case such a failure should occur, and apparent singleness should be the result.

If, as on theoretical grounds seems possible, the localization test serves to distinguish between conditions in which on the one hand the attribute of character only is abolished, and on the other hand either that of individuality alone or those of character and individuality together are lost; and if the compass tests (discrimination of two different tactile stimuli as double whether they are applied simultaneously or successively) serve to distinguish between conditions in which on the one hand either the attribute of character alone is abolished or the attributes of character and individuality are both destroyed, and on the other hand the attribute of individuality alone is lost: then a combination of the two tests should serve to distinguish between the three possible conditions—that in which the attribute of character alone is lost, that in which the attribute of individuality alone is lost, and that in which the attributes both of character and of individuality are lost.

In other words, for the compass test to be a complete one the answer of the subject should not only indicate that there is a "doubleness" about the stimuli, but it should also give data with regard to whether the doubleness is referred to two different spots on the skin or to one and the same spot. When the compass is applied in such a manner that its points fall synchronously upon two different spots and the touches are referred to by the subject as having "doubleness," we may assume that this is referred also to two different spots on the skin. But this is not necessarily the case if the compass points are applied successively with a short interval of time between them (let us say 0·5 sec.).

To meet this problem the following compass tests may be used. They require two compasses, and one arm of one of them is furnished with a small soft pad of leather sufficiently far removed from the point that it cannot come into contact with the skin. Sometimes two different spots are touched successively with a short interval of time between the application of the first and of the second point of the compasses; sometimes a single spot only is touched; and sometimes the point of the compass which is provided with the leather pad is touched on a single spot, and then immediately afterwards an additional touch is applied to the pad of leather by the second compass—the interval between the first and second touch here being the same as that between the application of the first and second point of the compass when two different spots are touched successively. The subject states that the touch is a double one applied to two different spots; that it is a single one; or that it is a double one applied to the same spot. In the second test sometimes one point of a compass is applied to a single spot; sometimes the two points of the compass are applied successively to two different spots; and sometimes two compass points (one of each compass) are applied successively very close together to almost the same spot. The subject again gives one of the three above answers.

The normal subject can distinguish between the different elements of these compass tests. If, however, the attribute of character is lost (without the abolition of the other attributes and without any other disturbance) the subject will, theoretically, be unable to distinguish between the successive touching of two different spots and the successive touching of nearly the same spot with the points of two different compasses. In both cases, theoretically, he may recognize the touches as double; but the synchronous touching of two different spots will seem to him to be single. Where the attribute of individuality is lost alone the subject should theoretically be able to distinguish correctly between the two points applied synchronously to two different spots; the two points applied successively to the two different spots; the points of two different compasses applied successively to nearly the same spot; and of course the single compass point applied to one spot. If the attributes both of character and of individuality are lost the results of the tests should theoretically be the same as in the case of loss of character only.

With loss of the attribute of position alone (without loss of the other attributes) normal results should theoretically be given to the different compass tests even when the patient is unable to make the attempt at localization.

In these theoretical considerations we have of course made the assumption that it is possible that one only of the attributes of the tactile sensation may be lost, or that one may escape from a destruction which overtakes the other two. If such a dissociation between destruction of the different attributes does not occur—that is to say, if they are so closely bound together that if one is destroyed or impaired the others are also destroyed or impaired—it is clear that no tests will serve to distinguish between them. Then the effects of all cortical lesions which destroy or impair the faculty of localization of tactile stimuli will give similar results—which may, indeed, differ in degree, but will not differ in kind.

It is interesting here to note the observations of Head and Holmes [1] on this point. They state that "in a certain proportion of cortical cases it does not matter whether the compasses are applied simultaneously, or whether an interval is allowed to elapse before the second point touches the skin. The power of recognizing the double nature of the stimulus is lost and no increase of the distance between the two points makes a constant or material difference to the accuracy of the answers. . . . Evidently he (the patient) has lost that faculty by which 'two-ness' is recognized, and it does not matter whether the points are applied simultaneously or successively. Now, whenever successive application of the two points is recognized, localization will be found to be intact. The power of appreciating two points applied successively is in reality the faculty of localizing two spots that have been stimulated one after the other. It is independent of the power of discriminating two stimuli which act upon the surface at the same moment." To this question we shall return in parts of this paper to be published later.

In this analysis of the faculties of localization and discrimination of tactile stimuli we have so far confined ourselves to what may be termed "negative" error. It is clear that there may be a difference between possible errors of localization in which the subject, even although he thinks his localization in each case to be correct, places a specific touch, now here and now there, indifferently upon the different positions in a restricted test, and possible errors of localization in which the subject constantly places a specific touch upon the same wrong position. Let us suppose that the test for accuracy of localization is one in which a small number of different spots is used, and that the tactile stimuli applied to them are given in an indifferent order in which no two consecutive stimuli are applied to the same spot. In the former case the

total average error of localization will be that of hazard, and if the answers to any one specific stimulus are examined it will be found that they vary amongst the possible answers—the individual average error of the answers to that stimulus still being that of hazard. But in the latter case the total average error might even be as high as 100 per cent., as might also be the individual average error of localization for each specific tactile stimulus used in the test. Thus let us suppose that three spots only are chosen for examination, and that the subject knows that there are three possible answers in the case of each tactile stimulus—only one of the answers being correct, that is, corresponding accurately to the locus of the stimulus. In the former case the subject will call stimulus "3" indifferently "1," "2," or "3"; and in a sufficiently large number of answers 33·3 per cent. will be given to each kind. That is to say, that of the whole series of answers 33·3 per cent. will be right; 66·7 per cent. will be wrong, and the wrong answers to each of the three stimuli will be equally divided between the two possibilities. But in the latter case the subject may always localize stimulus "1" at "2," stimulus "2" at "3," and stimulus "3" at "1." The average error will here be 100 per cent. for the whole series, and 100 per cent. for the answers to each specific stimulus, while the wrong answers to any one of the three stimuli will not be equally divided between the two possibilities.

In a case in which there is persistently a greater error than that of hazard it is clear that something more than the mere abolition of the faculty of localization (or of one of its factors) is present. There must be an actual distortion of it—an actual constant error, not an indifferent error. This error we may term a "positive" one.

On theoretical grounds we may assume for the moment that our hypothetical attribute of position may either be abolished or distorted by a cortical lesion. In the former case there should be no localization of a touch, even although its attributes of character and individuality are unimpaired. In the latter case localization may be present in these circumstances, but it may be inaccurate. That is to say, that the localization of a certain touch which has the attributes of character and individuality, but has a wrong attribute of position, may be done in an inaccurate manner, but the error will always be the same.

The method of testing localization for a restricted number of spots may bring out this type of error if it really occurs. The test in which the number of spots touched is not limited can hardly be expected to

do so, for there the error of hazard is about 100 per cent.; in such a case the only indication of this type of error is the personal opinion of the investigator that a certain tactile stimulus is always referred to a certain wrong position on the model. Records in which the number of different tactile stimuli are limited, as also are the possible answers, will give an error of hazard which is appreciably less than 100 per cent. (i.e., 66·7 per cent. where three different stimuli are used, 75 per cent. where four are used, and so on). If the average error in such records is constantly and appreciably greater than the error of hazard it may be inferred that the error is a "positive" one and not a "negative" one—to use the terms in the sense which we have already given to them. If such a record is analysed still further and the average individual error of localization for each tactile stimulus is obtained it may be found that these errors differ. Thus it might be that the total average error in the answers to the whole series of different stimuli is in fact about that of hazard, but that the individual average error in the answers to the stimuli which are applied to one of the spots is markedly greater than the error of hazard. A further analysis might indicate that in the case of the answers to this stimulus there is a preponderance of one specific wrong answer, and that the wrong answers to it are not evenly divided amongst the possible wrong answers

The following example from actual experiment brings out this point. It actually is a record of the answers to three different two-dimensional stimuli—flat objects of three different shapes applied to the palm of the affected hand:—

123231312321312132321213213232123132312123
132321213221312123121312211111112123223112

212313123123231213123123231212312132132313
333222223223311312222222222312111212112211

In this example the number of wrong answers is 51 out of a a total of 84 answers—an average error of about 60·7 per cent., the error of hazard being 66·7 per cent. The individual average error in the answers to "1" is about 35·7 per cent.; that for "2" is about 57·1 per cent.—smaller than the error of hazard; and that for "3" is about 89·3 per cent.—much greater than the hazard error. Each of the three different stimuli is given 28 times, and when the wrong answers to "2" are analysed it is found that "2" was called "1" 5 times, and was called "3" 11 times—there, therefore, being a marked disposition to call "2" "3" when it is wrongly named. Of the wrong answers to "3," 8 are called "1," and 17 are called "2." In this

case there, therefore, seems a definite confusion of the stimulus "2" with the stimulus "3" and the error is too great to be due to hazard. As a matter of fact the individual average error per cent. in the answers to the stimulus "3" on six consecutive days was 75, 85·7, 89·3, 82·1, 78·6, and 71·4—in each case above, and sometimes markedly above, the error of hazard, which here was 66·7 per cent.

What may be supposed to happen in our so-called "positive" error of localization is that the spot indicated by the subject as corresponding to the position of the touch which he perceives lies in some constant relation to the true corresponding position. As Head and Holmes point out, Russell and Horsley [1] state that this is the case in disturbances of localization by cortical lesions. The former observers, however, believe that their own failure to discover such a uniform tendency to erroneous localization is due to the avoidance of the "groping" method of testing localization—the method in which the subject (not seeing the spot stimulated) tries to touch with his other hand the spot to which the tactile stimulus has just been applied—and to the elimination of error due to defective recognition of the posture of his limb by the patient. They say, "We cannot insist too strongly that, when localization is defective from lesions of the cortex, the stimulus is not localized in some false direction, but the patient has a vague and uncertain idea amounting in some cases to complete ignorance of its position."

Another point in connection with our hypothetical attributes of character, individuality, and position may be noticed. The attribute of position has obviously attached to it (or has as a part of it) permanent memory. It is the relating of a tactile sensation, the character and individuality of which are presupposed, to a certain part or point in the subject's "schema" (to use Head's term) of the surface of his body. For the accuracy and constancy of the attribute of position of touches applied at different times to the same spot of the skin permanent memory would seem to be necessary. In a similar manner permanent memory would seem necessarily associated with the attribute of individuality—perhaps the two attributes are closely connected, at any rate as regards this permanent memory. But is permanent memory of necessity connected with the attribute of character?

Theoretically, at any rate, it is possible to suppose that this sort of permanent memory is not necessarily attached to the attribute of character. Thus it may be conceded that tactile stimuli applied to different spots on the skin condition activities in the cortical mechanism which are in some manner different. The parallel changes in

consciousness which accompany these changes in activity may also be different, and in short, the sensations conditioned by the different stimuli are recognized in consciousness to be different—if they are present in consciousness at the same time, and can thus immediately be compared the one with the other. But if the different stimuli are not applied synchronously it would at first sight appear that an element of memory is necessary for the bringing together of the sensations which they subtend and for their comparison in consciousness. This is, perhaps, not necessarily so.

If the sensations conditioned by tactile stimuli were of infinitely short duration in consciousness, the comparison of two asynchronously applied stimuli would appear to be inconceivable without a link of memory. But it is probable that the sensation conditioned by a tactile stimulus has a definite duration in consciousness—there is a sort of "after-discharge." One of us has shown that electrical stimulation of a point in the "motor" area of the cortex cerebri is followed by a state of facilitation during which the point remains more excitable than usual to the electrical stimulus; and that the duration of this state—which is probably that of the "facilitation" which has been postulated for cortical "motor" (and also "sensory") activities—is a comparatively short one, 10 min. to 20 min. for liminal stimuli. Now, if we suppose that the activity which underlies the sensation in consciousness of a tactile stimulus may persist, slowly dying, after the withdrawal of a stimulus, and if this continuance of activity is paralleled by a persistence of the change of consciousness, another stimulus applied to a different spot during the continuation of the "sensory after-discharge" would be paralleled by a change in consciousness which would synchronize with the dying after-effect of the first. In a manner the two sensations would be present synchronously for comparison in consciousness. But it must be noted here that the dying after-effect of the sensation in consciousness may well be likened to a sort of transient memory; and that the after-discharge and dying state of facilitation of the physiological mechanism ("motor") might in a sense be regarded as the physical counterpart of such transient memory. It is not, perhaps, altogether unwarranted to apply this idea of facilitation to the "sensory" mechanism, for it seems to be present in the mechanisms of the post-central convolutions which are usually looked upon as "sensory" in function.

This state of "facilitation" may possibly be one of the physiological factors which underlie the psychical attribute of "character" in the

sensations conditioned by tactile stimuli. The recognition of different touches simply as different apart from the recognition of their locus may be conditioned in part on the physiological side by the state of facilitation of the mechanism. Thus a second stimulus applied sufficiently soon after a first to the same receptors should give a greater response; stimuli of different intensity applied at different times to the same receptors are recognized to differ; if now stimuli of the same intensity are used and this is within the knowledge of the subject, stimuli applied sufficiently close together in time to different spots may be recognized as different. For if two stimuli of equal intensity are applied soon one after the other to the same spot the sensation conditioned by the second will appear to be more intense than that conditioned by the first. If two equal stimuli are applied one after the other and the sensations conditioned by them do not appear to the subject to be different in intensity, he may infer that the stimuli have been applied to different spots. This is, perhaps, too far-fetched, and at any rate such a factor could not be the sole condition of difference in character of touches, for it would be hard to explain by it the recognition of doubleness of contact when two different spots are touched simultaneously.

Before concluding this section of the paper we cannot refrain from a speculation which we think may lead into interesting paths of investigation.

The psychical process of the localization of sensations is, as it were, a process of apprehension, and this seems to be conditioned by three chief sets of factors—the sets of factors associated respectively with the "character," "individuality," and "position" of the sensation.

But the process of apprehension is associated with other than the more or less simple sensations which are conditioned by what for practical purposes may be regarded as one-dimensional tactile stimuli; that process is also associated with the compound tactile (and deep pressure) sensations which the stimuli engendered by two-dimensional objects condition—and with the compound tactile, deep pressure, and kinæsthetic sensations conditioned by the stimuli which three-dimensional objects engender.

And, again, the process of apprehension is not restricted to the sensations conditioned by the activities of the sense organs of the skin, subcutaneous tissues, muscles, tendons, and joints; it is thus also associated with the sensations conditioned by the activities of such organs of special sense as the retina and the cochlea.

The interesting question therefore arises whether these other processes (which are in some manner, perhaps, comparable to the process of localization) may be analysed in terms of the three same sets of factors—character, individuality, and position.

In the case of the apprehension of the sensations conditioned by two-dimensional objects pressed upon the skin we have already satisfied ourselves that this obtains; and we have a little evidence which suggests that the process of apprehension of printed words and letters may also be analysed in terms of these factors.

Thus, for the proper description by the subject of flat objects of different shapes (of which he is allowed to be aware only through the sense organs of the skin and subcutaneous tissues), he must be aware of the character of each object—its difference with regard to the others, the individuality; its sameness each time it is pressed upon the skin; and the position—that is, its relation to one of his "schemata." It must be noted here that in the process of localization the factor of "position" refers not at all to the place upon the body to which the stimulus has been applied, but to the place of the sensation within the subject's schema of the surface of the body. In this sense the word may also be used to denote one of the factors (or sets of factors) in the process of apprehension of two-dimensional objects; that is, it may be used to express the place of a certain two-dimensional object within the subject's schema of such things.

The heard or seen word is apprehended and recognized, and in the process of recognition there may, perhaps, be discerned the same three sets of factors. Thus, a certain word must in the first place be recognized as different from all others—there must be factors of character in the recognition of words; and it must be recognized as similar to itself each time it conditions sensations (either visual or auditory)—it must have individuality; while, finally, it must be related to the subject's schema of words—it must have position. With the written or printed letter or the unitary sounds in heard speech these three factors may, perhaps, be relatively simple; but with the heard or seen word they are obviously much more complex. This complexity is increased by the fact that certain similar words may have different "positions"; thus the printed word "smack" has its factors of character and individuality but many positions. Its meanings are various: "a small ship, a loud kiss, a sharp noise, a smart blow, a taste, a tincture, a small quantity," and so on—to take only its meanings as a substantive. Here the positions of the word in its recognition are probably a factor conditioned

not only by the seen word itself but by the context—its environment or "background." [It would, perhaps, be more correct to say that many different words have the same character and individuality, than to say that a certain word has many different positions.] In a similar manner heard words may have similar characters and individualities but different positions—such an example as "sow," "sew," is sufficient to demonstrate this.

Quite another form of complexity lies in the fact that words which have different characters and individualities may have the same position. Thus "gauge" and "measure" may have identically the same meaning. It is interesting to note that, in the case of two words which have many meanings, but only one common to both, the effect of the context is a predominant factor in the conditioning of the position.

Of course the schema of language is very much more complex than the schema of the loci of cutaneous sensations, but we suggest that there is much similarity between the two. The position of a word in the language schema (or schemata) may be related to all which we denote when we talk of the meaning of a word; but it must be observed that a single word may be related to many different schemata, each of which forms a part of the complex which we may term the schema of heard and seen language. The position of a word may be common to many schemata; and we may make a simple model of the relation between the position of a word and the different schemata to which it is related by figuring the schemata as geometrical planes, and the position of the word as a geometrical point. We may then figure the relation between a word and its schemata by supposing that the different planes intersect each other at a single point—the position of the word.

In the case of language the position of a word is common to at least two sensory complexes—the seen word and the heard word. Indeed, it must be common to more than these two, for the position of a word in the process of recognition must be common to the different forms in which the seen word may be presented (that is, the written word and its different forms, the printed word and its different forms, the word written or printed in different colours of ink, the word as recognized by touch, the word as written or printed in different alphabets; for instance, in shorthand or in the raised characters of the Braille system of printing for the blind—the corresponding word in various different languages, and so on).

The subject's schemata of different classes of sensations seem probably to be (as it were) catalogues of common elements in many different sensations. This is, perhaps, peculiarly so in the case of the language schemata, but it must not be forgotten that it also obtains in so comparatively simple a schema as that in which the cutaneous sensations are related together in the process of localization. Thus the sensations conditioned by tactile stimuli, by stimuli of heat and of cold, and by pain stimuli, all of which are applied to a given small area of the skin, are referred to a common locus in the process of localization. That is to say, that these sensations have a common factor of position in their localization. In other words, each of them is referred to the same part of the subject's schema of the surface of his body.

We would like to suggest that the method of experiment used in this investigation is eminently adapted for the proper examination of these different subjective schemata, and for the analysis of the factors in the apprehension of sensory complexes—either the relatively simple process of localization (which seems capable of analysis in terms of three or more sets of factors) or the relatively complex process of apprehension of heard and seen language.

That method—which we believe to be a new one—necessitates a subject in which there is some disorder of the process which is to be investigated. Given this condition, the method consists in the restriction of the number of different stimuli presented to the subject (be they tactile stimuli, the stimuli conditioned by two-dimensional objects, auditory stimuli, visual stimuli, and so on), and in a restriction the number of answers which the subject is allowed to give. This restriction of the answers is obtained by allowing the subject to know the number and the different forms of the stimuli which are to be presented to him, but not the order in which they will be given. Accurate records of the answers (whether they be right or wrong; and, if wrong, the nature of the reply) are taken, and are then finally analysed after a correct estimation of the percentage error of hazard. The answers to the stimuli are scrutinized in the first place with reference to their order in series. Attention is paid to the possible error of giving the same reply consecutively to consecutive stimuli of different sorts—this type of error denoting defect in the factor of character—and to the possible error of giving different consecutive replies to consecutive stimuli of the same sort—this type of error denoting defect in the factor of individuality. In the second place the replies to each individual sort of stimulus are scrutinized after determination of the

hazard proportion of each possible answer to the sort of stimulus which is being analysed. A reply which is given in a greater proportion of times than the hazard proportion may be termed a positive one, and where the reply is incorrect it may then be termed a positive error. The occurrence of positive error seems definitely to point to a distortion of the position factor in the apprehension of the sensation conditioned by the stimulus which is being analysed.

This method of investigation, which may be suggested as one suitable for use in all cases of disturbance of the process of apprehension, may be termed the method of restricted test analysed in terms of positive error by reference to the error of hazard.

III.—Methods employed.

(1) *The Subject of the Experiment.*

J. H. L., born in 1886, wounded on October 26, 1914, by a rifle bullet through the left side of the head.

The wound of entry is represented by a small round hole in the skull, and about 1·5 cm. in diameter. Its nearest point to the central line lies about 5 cm. from it (on the left side of the skull), and the distance between the nasion and that point on the central line of the surface of the head which is cut at right angles by a line passing through this wound is about 12 cm.

In a similar manner the wound of exit lies (at right angles to the central line) 3 cm. to the left, a point on the central line—the distance between the nasion and that point being about 29 cm.

There is a trephine opening in front of the wound of exit. Its longest axis is parallel to the central line of the head, and is about 7 cm. long. Its most anterior point lies about 3 cm. to the left of a point on the central line which is about 22 cm. posterior to the nasion; its breadth is about 4 cm.

A description of the case is given in a later section of this paper. The experiment was begun on January 7, 1916, more than fourteen months after the infliction of the wound.

(2) *Methods of Examination.*

In this experiment the accuracy of the subject's localization of tactile stimuli of different intensities, of painful stimuli, and of stimuli of heat and of cold, was registered at different times. So, too, was the

accuracy of his responses (as regards doubleness or singleness) in the compass test, and the accuracy of his recognition of three differently shaped flat objects of indifferent temperature placed in contact with the surface of the palm.

In testing the accuracy of localization of tactile or other stimuli, we made use of the Henri method as modified by Head and Holmes. Stimuli were applied either to the dorsal or to the palmar aspect of the hands (the right hand being that which was affected), the arm first being passed through the opening of a screen which prevented the subject from seeing the spots which were touched. A model held his corresponding hand in the same posture as that of the subject. This hand was within the subject's field of vision, and he indicated upon it with a pointer (held in the other hand) the position which he thought to correspond to the location of a tactile stimulus which had just been applied to his own hand. The normal hand was withdrawn from behind the screen (in order to indicate the localization when control observations were made upon it).

For the purposes of our experiment, and for ease of registration, we restricted the loci of the stimuli to nine different specific spots on each of the second, third, fourth, and fifth digits of either hand. Of these nine spots, in each case three were situated on the dorsal aspect of the finger (see fig. 1), and were so placed that a spot lay on the skin about midway between the two extremities of each of the three phalanges. In the case of each finger six different spots were situated upon the palmar aspect. Three of these spots were placed, as in the case of those on the dorsal aspect, one about midway between the two extremities of each of the phalanges (see fig. 2); the remaining three spots (see also fig. 2) were placed on the folds of the skin near the metacarpal-phalangeal, and the two inter-phalangeal joints respectively—that is to say, about midway between pairs of the other spots. All the spots lay upon that dorso-ventral plane which passed through the long axis of the finger.

This gave us three sets of three different spots each, and we numbered the different spots in each set " 1," " 2," and " 3 " in their order from the extremity of the limb towards the trunk. The spots were permanently marked with silver nitrate; and spots corresponding to them were marked upon the fingers of the model.

In an experiment a stimulus was applied to a certain spot and the subject then (a) failed to give any response (this failure being recorded), or (b) tapped the end of his pointer upon the table to indicate that he

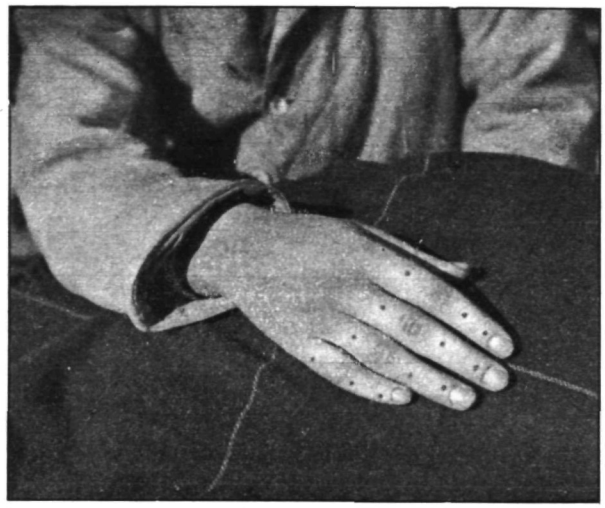

FIG. 1.—Photograph of the dorsal aspect of the subject's right hand. The three spots on each finger ("dorsal sets of spots") are shown, having been marked with ordinary ink for the purpose of the photograph.

FIG. 2.—Photograph of the palmar aspect of the subject's right hand. The six spots on each finger ("ordinary" and "untrained" sets) are shown with the exception of the distal spots (spots "1" of the "ordinary sets") on the index and ring fingers, which are covered by the observer's finger-tips. On the middle finger the spots from left to right (that is, distal to proximal) are "spot 1" ("ordinary set"); "spot 1" ("untrained set"); "spot 2" ("ordinary"); "spot 2" ("untrained"); "spot 3" ("ordinary"); "spot 3" ("untrained") The black patch on the palm was the mark used in training experiments on discrimination of two-dimensional objects not here described.

was unable to make a localization of the touch which he yet perceived, or (c) touched with his pointer the marked spot upon the model which he thought corresponded in position with that to which the tactile stimulus was applied upon his own hand. If no localization was made (although the subject was aware of the stimulus) a mark was placed upon the record under the corresponding number of the spot which was stimulated, and that stimulus was not repeated. When no response was given—the touch not being perceived—the stimulus was repeated. If a localization was made the corresponding number which we attached to the spot indicated on the model was written below the number of the spot touched on the subject. "Dilemma" could usually be detected by observing the movements of the pointer, and when it occurred was registered on the records. The examination was conducted in silence, and throughout the whole duration of the experiment the subject was never allowed to see a record, nor on any occasion was he allowed to know whether his reply had been right or wrong. Owing to the slight contracture of the affected fingers one of the observers held the finger that was being examined in a posture of extension.

In the first part of the experiment we gave the stimuli to the different spots in a series, the order of the elements of which ("1," "2," and "3") was selected by lot. In consequence of this there were slightly unequal numbers of the three different spots in a series, and sometimes a certain spot would occur several times in immediate succession. In the succeeding parts of the experiment (not here published), we used a new set of records in which, while the order of the spots was selected by lot, no two consecutive ones were the same and in which equal numbers of each spot were present in each record.

We usually examined the accuracy of localization of touches for one of the sets of three spots on each of the fingers separately—the subject being allowed to know which finger was being touched in any one test. At first we used records in which twenty-five consecutive tactile stimuli were applied to the three different spots (an average of about 8·3 stimuli to each spot). Later we increased the number of stimuli in a series to forty-two, of which exactly fourteen were applied to each of the three spots.

The stimuli were applied at the rate of about one every five seconds, and intervals of one minute each were allowed to elapse between the series of stimuli which were applied to different sets of spots.

The sets of spots on the different fingers were examined in a constant order in the ordinary daily tests. First, two palmar sets—one on each

of the third and fourth digits of the normal left hand. Then a palmar set on the second, third, fourth, and fifth right digits in that order. Then the dorsal sets of spots on these six fingers in the same order as before. Finally, for purposes of control, the palmar set of spots on one of the normal fingers was again examined, and occasionally the palmar set of spots on the second right digit.

For purposes of control, and to obtain additional data, from time to time we did this test without allowing the subject to know which finger was being touched, but allowed him to know the position of the twelve spots which were to be touched upon the four fingers. In this test (as a rule) no one finger was touched twice consecutively, and the order in which the fingers were touched was otherwise selected by lot—equal numbers of stimuli, however, being applied to each finger in the test. In this test usually 84 stimuli were applied (sometimes 168) in consecutive series of 21 each, with intervals of one minute between the series.

The tactile stimuli used were given by pressing hairs, each of which exerted a constant pressure when force sufficient to bend it was employed (the hairs were of different stiffnesses in different tests) on the selected spots; painful stimuli by stabbing the spot with the point of a needle; heat and cold by applying a hot or cold flat metal surface (*circa* 5 mm. in diameter) so gently against the spot that it gave the least possible recognizable sensation of touch. We also on one occasion gave tactile stimuli by pressing the open end of the cap of a fountain-pen against the skin in such a manner that it encircled, but did not touch, the spots used in the other experiments. In the first series of records we used as a constant stimulus on consecutive days a hair of stiffness just insufficient to give a painful sensation when applied to a spot on the normal palm; in the following series of experiments we used a small apparatus for giving constant pressure-touch stimuli. This, which we made ourselves, consisted in a rod (the end being a bad conductor of heat) which worked in a hollow holder against an elastic band.

The normal error of localization of tactile stimuli applied with these instruments which we used in the day to day tests is, in the normal subject, about 0·0 per cent. on the palmar aspect when the test is restricted to a single finger. When it is not so restricted to a single finger, but when the possible spots on each finger are restricted to three, the normal error for the palmar aspect of the fingers seems to be about 8 per cent. The tactile stimuli are rarely localized on the

wrong finger (when they are the finger touched is usually the third or fourth digit, and the stimulus is referred to the fourth or third) and the error usually consists in wrongly placing a stimulus upon the right finger. The spot thus wrongly localized is usually "spot 3"—i.e., that of the three nearest to the trunk, less often "2," and seldom or never "1"—that situated on the pulp of the terminal phalanx. The error is usually made by localizing "3" on "2"; less often by localizing "2" on "3"; seldom or never by localizing either "2" or "3" upon "1." We have never, on our own persons, seen an error in which a tactile stimulus delivered with these instruments was localized wrongly both in regard to the finger and to the position of the spot on the finger.

(3) *The Method of Training used in the Experiment.*

The general aim which we had before us was the investigation of the possibility that a lost "sensory" function, probably of the cerebral cortex, can be regained—just as recovery of "voluntary" movement may occur in monkeys and higher apes after a cortical lesion of the so-called "motor" area. Although such a recovery of a lost "sensory" function has not yet been observed to occur "spontaneously," it is possible that it might do so under the influence of training. Tests of the accuracy of localization, &c., of tactile stimuli before and after such an attempt at training may yield evidence as to its effects.

In applying the training a single finger was selected and it only was trained at that time. Not only this. The training was applied only to one of the three sets of three spots on that finger—the other two sets remaining untrained. The three spots which were trained were, in every case, those situated about the middle points of the pads of the fingers which lie over the middle of the palmar aspects of the three phalanges.

In this manner we were able to compare the accuracy of localization of stimuli applied to the "trained" spots after the training with that of corresponding but untrained spots on the other fingers; with that of the untrained spots on the back of the trained finger; and with that of untrained spots on the palmar aspect of the trained finger (these untrained spots lying on the folds in the skin near the metacarpal-phalangeal and the two interphalangeal joints).

The training was performed in the following manner: An ordinary localization test having been done for the spots which were to be trained, the subject was allowed a short interval of rest. Then he was told

that spot " 1 " was going to be touched and that he was to concentrate as much as possible upon his experiences during the stimulation—trying to realize the peculiarities of the stimulus, &c. That spot was then slowly stimulated 10 or 20 times in succession with the ordinary instrument—and he was allowed to see each alternate touch being given by the silent removal of the screen. In the same way 10 (or 20) successive touches were applied to each of the other spots—" 2 " and " 3." After a short interval of rest the subject was allowed to look at his finger while 50 successive touches were applied in an indifferent order to the three different spots. Then, after another interval of rest, the ordinary test of the accuracy of localization of tactile stimuli on these same three spots was again done—the subject now not being allowed to see his hand, and having to point to the corresponding spots on the hand of the model. During the training the subject was at one time told to concentrate his mind especially upon the similarity of the stimuli which were then being applied consecutively to the same spot. At another time he was told to concentrate upon the dissimilarities of stimuli which were being applied consecutively to different spots.

This training was usually done in the evenings of a series of consecutive days; sometimes it was performed repeatedly (at two-hour intervals) on the same day. During and after a period of training the ordinary tests were applied in the morning.

(4) *The Course of the Experiments.*

In our first series of tests, on 13 consecutive days we investigated the accuracy to localization of the spots on the palmar and dorsal aspects of each finger of the right (affected) hand of the subject, as well as the corresponding spots on the palmar and dorsal aspects of two of the fingers of the left hand. The stimulus used was the same throughout—that given by pressing a hair against the spot (the hair being a fairly stiff one, but not one which gave a painful stimulus on the normal hand). In addition we used the test in which the stimulus was applied to spots on any of the fingers.

On the fifth, sixth, and seventh days of the series the three palmar spots of the right index finger were trained. The accuracy of localization for tactile stimuli before the training was on this finger intermediate between that of the most defective and that of the least defective finger—but nearer to the former than to the latter. On the seventh day of the series the accuracy of localization on the right index finger was tested (after the training in the morning) every hour from 11 o'clock

in the morning to 9 o'clock at night. Thereafter the tests were continued as before; but on the ninth day of the series the accuracy of localization on the right index finger was tested thrice during the day at four-hour intervals; on the tenth day of the series it was tested four times during the day at three-hour intervals; and on the twelfth day of the series it was tested seventeen times during the day at half-hour intervals. In addition to this, on the tenth, twelfth and thirteenth days of the series the accuracy of localization of tactile stimuli was tested for the set of three untrained spots on the palmar aspect of the index finger (that is, the spots situated near the three joints)—and for the corresponding spots on the other fingers. While on the thirteenth day of the series the training of the spots of the palmar aspect of the right index finger was performed again, on this occasion the training being done four times during the day at two-hour intervals.

On the fifteenth day of the test (three days after the fourteenth) we asked one of our colleagues (Dr. W. H. R. Rivers) to make an examination of the affected hand before making him aware of the nature of our experiments. He came to the conclusion that there were gross errors of localization of tactile stimuli which were applied to the palmar and dorsal aspects of the right hand.

IV.—On the Conclusions which may be drawn from the First Part of this Experiment.

For the easier reading of this paper, we think it best to give here the conclusions which, we believe, may legitimately be drawn from the results obtained in that part of the experiment with which we are dealing—reserving the more detailed analysis of this part of the experiment to the following section of the paper.

It must be clearly understood in the first place that we have no definite knowledge of the situation, nor of the extent, of the cerebral injury—save only that in part that injury is situated in the parietal lobe of the left cerebral hemisphere. We have also no definite knowledge of any changes which may have taken place in the cerebrum during the course of the experiment, but we think that, as we started the experiment fourteen months after the infliction of the wound, any possible process of recovery should by that time have ceased.

The part of the experiment which we consider here is a small portion of the whole. We give the facts as they were; and our conclu-

sions are drawn only from the facts here given, and they are drawn irrespective of the facts obtained later in the experiment—save only that we know that a similar improvement of the accuracy of localization of tactile stimuli occurred when we selected another finger for training.

Now with regard to the state of the subject at the commencement of the experiment:—

The man was unable accurately to localize tactile stimuli which were applied (amongst other places) to the palm of the right hand and to the palmar aspects of the right fingers; the defect of localization was, in fact, gross. He was not, however, unable to attempt a localization. In fact, when a spot in that region was touched, the subject usually made a localization—even although that localization was often a wrong one. He, occasionally, was unable to make the localization at all when the test was limited to a certain small number of spots, but this inability lasted only for the first eight days of the experiment and the stimuli which he was unable to localize were only about 10 per cent. of the whole. Dilemma in the reactions of localization also occurred, but this also decreased as the experiment proceeded. Neither dilemma nor confusion occurred when the test was an unrestricted one—that is, the ordinary clinical method.

A striking characteristic in some of the cases cited by Head and Holmes was that the subject was frequently unable to make the localizations of tactile stimuli. In the present case there is no such inability—but a large proportion of incorrect localizations is made. Recently, we have had the good fortune to be able to investigate another similar case. In this second instance the error of localization is very large; but there is an almost complete absence of dilemma, and the proportion of instances in which localization cannot be made is small. In this second case a remarkable feature is the apparent certainty with which the subject makes the localizations. So great was this, that at first we suspected that he was making them by hazard. But the records show that this probably is not the case. We may conclude that in the subject of the experiments here described the effect of the lesion has not been to wipe out the function of localization of tactile stimuli for a certain part of the body, but only to destroy or to distort certain elements in the complete function.

In the complete process of localization of tactile stimuli we may distinguish three elements or attributes (as regards localization) of the sensation conditioned by each stimulus. These are: (1) the element of "character" (whereby the sensations conditioned by differently located

tactile stimuli are recognized as in some manner different from each other); (2) the element of "individuality" (whereby the sensations conditioned by tactile stimuli which are applied at different times to the same spot on the skin are recognized in some manner to be similar to each other); and (3) the element of "position" (whereby the sensation conditioned by a certain tactile stimulus is recognized as in some manner connected with a definite point in the subject's schema of the surface of his body). As in this experiment the spots which were touched lay upon the fingers of the right hand we may recognize at least two factors in the element of position. The first of these is the place of the touched spot upon the finger. But as there were four fingers all very much alike—that is, four different possible places for each spot—there must be a factor of "finger" in the position of the spot, a factor whereby the subject recognizes that in some manner the tactile stimulus has been applied to a spot on a certain finger. The elements of character and individuality are possibly more fundamental than the elements of position. The latter, perhaps, are those which relate the sensation conditioned by a specific tactile stimulus (with its character and its individuality) to the schema of the surface of the body.

As it is obvious that if the element of "position" in the localization of tactile stimuli is destroyed, the subject should be unable to make any localization of them, and as in this experiment such localizations were made (although often incorrectly), we may conclude that at any rate the element of position was not abolished. But it is yet possible that in our case the elements of position were distorted, although not eliminated. Our results definitely point to this conclusion.

Thus, in the first place, the error of localizing stimuli, which were applied to certain of our chosen spots, was greater than the error of hazard. Such an error may be termed (for our purposes) a "positive" one; and its occurrence clearly indicates that in these instances there was not a mere elimination of an element in localization, but a distortion of it. Thus the tactile stimuli, which were applied to a certain spot (e.g., spot "3") on a certain finger might be definitely thought by the subject to have been applied to another spot (e.g., "2") upon the same finger; and every time (or nearly every time) a tactile stimulus was applied to that first spot, it might be localized by the subject upon the second. In such a case what is at fault is the factor of "place," or "position," within a certain schematic field, of the sensation conditioned by the tactile stimulus, and the error is a definite one.

In the second place, the error of localizing a touch upon the correct

finger (that is, within the correct cutaneous field) was in some cases greater than the error of hazard. This shows that here also there was no mere partial elimination of a factor in the element of position, but a definite distortion of that factor. The subject definitely thought that a large proportion of the tactile stimuli which were applied to spots on a certain finger were applied to spots on a certain other finger.

It is quite possible that such distortions of the elements of position in the localization of tactile stimuli might be sufficient to account for the badness of localization in such cases as that under consideration, even if the elements of character and individuality in the tactile stimuli were perfect. But in this case distortion of the elements of position can hardly have been the sole condition of the badness of localization.

Thus the subject at first repeatedly failed to recognize the differences between differently located tactile stimuli, which were applied in a consecutive series. Thus he might make the same localization—give the same answer—to each of a long series of tactile stimuli, no consecutive two of which were applied to the same epot. This definitely shows that one of the conditions of the badness of his localization of tactile stimuli was the failure to recognize differently located stimuli as in some manner different; in other words, the element of character in the localization of the tactile stimuli was at fault.

Again, the subject at first repeatedly failed to recognize the similarity between the elements of consecutive series of tactile stimuli which were applied to the same spot. Thus at times he would localize series of similar stimuli upon different spots, no consecutive two of which were the same. Here the element of individuality in the localization of tactile stimuli is at fault; the subject is unable to localize correctly a certain specific stimulus, but his error is not a constant one; when this stimulus is repeated in consecutive series, he localizes it now here, now there.

Thus the disturbance of localization of tactile stimuli in this case was probably a mixed one as regards the different elements in that localization. In the first place there was a definite defect in the elements of character and individuality in the localization of tactile stimuli; and in the second place there was a defect, amounting in some cases to positive error, in the element of position.

Such being the condition of the subject, we set ourselves to train selected spots upon the palmar aspect of one of the fingers. The training was directed to improve the elements of character and individuality of the spots, and to improve the factor of "place on the

finger" in their positions: but no direct attempt was made to improve the factor of "finger" in their positions, nor to improve the elements in the localization of any of the spots on the other fingers.

The result of this training was twofold. In the first place there was a very marked improvement of the localization of tactile stimuli on the trained spots both as compared with the accuracy of that localization on the same finger before the training, and with the accuracy of localization upon the other fingers after the training. In the second place there was a much smaller general improvement of the accuracy of localization on the other fingers as compared with their individual accuracies in the records which were taken before the training of the right index finger was commenced.

Of the three spots which were trained upon this finger, one showed an improvement which was not greater in degree than that of the improvement which occurred in the untrained spots of the other fingers. This was the spot on the basal phalanx—"spot 3." The two remaining spots—those on the distal and middle phalanges—"1" and "2"—showed a very great improvement in the accuracy with which tactile stimuli which were applied to them were localized. If the increase in the proportion of correct answers after the training is expressed as a percentage of the correct answers which were given before the training, we obtained a measure of the degrees to which the different spots improved. The improvement of localization on spot "1" is thus about 62·5 per cent.; that on spot "2" is about 110 per cent.; and that on spot "3" is about 13 per cent.

Thus the three trained spots show very considerable variations in the improvement of localization which they exhibit. We can only say that in the case of two of them that improvement is great, and in the case of the third slight; for although the improvement of spot "1" seems from these percentages to be smaller than that of spot "2," there was no scope for greater improvement; after the training the localizations on spot "1" showed no inaccuracy at all.

The inference from this is that the three trained spots show marked independence amongst themselves, and the improvement of one of them is not accompanied *pari passu* by improvement in the others.

In this experiment the tactile stimuli were applied to similar sets of three spots on the palmar aspect of each finger. Thus the four spots "1" on the four fingers have some resemblance amongst themselves; as have also the four spots "2" and the four spots "3." A slight (apparent) general improvement in the accuracy of the localization of

tactile stimuli upon these spots occurred in the other fingers after the training of the palmar set of spots on the right index finger—was this (apparent) improvement conditioned by that training? Later in this section of the paper we analyse this apparent improvement in the untrained spots. It seems that it was possibly not a true one, but due probably to the disappearance of that type of error in which the subject indicated that he was unable to make a certain localization. Ignoring this correction, we shall here assume that the improvement was a true one.

Had it been conditioned by the training of the spots on the index finger it would have been expected that on the other fingers the improvement occurred chiefly for spots "1" and "2"—those which showed most improvement on the index finger after the training. This was not the case. Of the three spots "1" on the three untrained fingers one (on the fourth digit) showed an improvement of about 14 per cent. only; the two others were actually worse after the training of the index finger. Of the three spots "2" on the untrained fingers, one (on the fifth digit) showed an improvement of about 9·7 per cent. only; the other two were about 12 per cent. and 16 per cent. worse than before. The general improvement in the three untrained fingers was referable to an improvement in the accuracy of the localization of tactile stimuli upon the spots "3"—those which corresponded to the trained spot which showed only a slight improvement.

From this we may infer that the marked improvement in the accuracy of the localization of tactile stimuli upon two of the trained spots was not accompanied by a corresponding improvement of similar spots on the untrained fingers.

This method of analysing the errors of localization and directing the examination, as we here are doing, chiefly to possible interdependencies of errors (or of relative changes in error) is really an investigation of the possible elements in the normal process. If the changes in the accuracy of localization of tactile stimuli upon two different spots show no dependence the one upon the other these two spots to a certain extent must be regarded as functionally independent. It is true that stimuli which are applied to them may have common elements or attributes (such as the common element "right index finger" in the complete localization of two tactile stimuli applied to two different spots upon that finger); but certain of their elements must be peculiar to themselves.

Now, after the training of the spots on the right index finger, our

subject was able to localize stimuli applied to them more accurately than before. It is possible that the effect of the training was to give him a new schema of the cutaneous field upon which these spots lay; or perhaps to give him a schema in which there were only three spots, one far from the palm of the hand, one nearer the palm, and one yet more near. It is clear that such a schema would possibly serve equally well for the placing of tactile stimuli which were applied to another set of three spots on the same finger—a set obtained, as it were, by shifting our three original spots each one half-phalanx length nearer to the palm of the hand. In other words, do nearly similarly located spots on the trained finger take part in the improvement of the accuracy of localization of tactile stimuli which are applied to them?

Our results show that this is not the case. When the accuracy of localization of tactile stimuli is investigated for untrained sets of spots (which are similarly arranged to the trained spots on the finger) no improvement *pari passu* with the improvement in the trained spots occurs in them. Had such an improvement occurred it would have been expected that the "untrained" set of spots on the trained finger would have showed greater accuracy in the localization of tactile stimuli upon them than spots similarly situated on the other fingers; and that, of the three "untrained" spots on the trained finger, that which corresponded to the trained spot "1" would have shown the greatest accuracy of the three. As a matter of fact, we found that the "untrained" spots on the trained finger were far less accurately localized than the corresponding spots on the other fingers, and that, of the three untrained spots on the trained finger, the spot which corresponded to the trained spot "1" was the least accurately localized.

From this we may infer that the improvement in the localization of a set of spots on a finger after training does not extend to an untrained set of spots similarly situated relatively to one another upon the same finger.

In this first part of the experiment we also used a third set of spots on each finger—that set which lay on the dorsal aspect. The three spots of this set corresponded in position exactly (or very nearly exactly) with the ordinary spots on the palmar aspect. The only difference between the two sets was that one was situated upon the palmar and one upon the dorsal aspect of the finger.

Now the investigation of the accuracy of localization in the dorsal sets of spots on the fingers after training of one of the palmar sets of spots presents points of interest. In the first place, the training

of a set of spots on one aspect of a finger is accompanied by an increase of the accuracy with which tactile stimuli are localized upon them. Does this increase apply also to similar spots on the dorsal aspect of the same finger? In the second place, if one effect of the training of the palmar spots on the right index finger is the perfecting of the subject's schema of that part of his cutaneous field, and if at the same time the relation between that part of the field (i.e., palmar surface of right index finger) and neighbouring parts (i.e., palmar surfaces of the other fingers of the same hand) is also improved in the subject, an interesting possibility arises. The subject had before his eyes the palmar aspect of the model's right hand. To this object he related the tactile stimuli which he experienced. The right index finger was improved by education, and that lay to the right of the other three fingers. But when the spots on the back of the hand were tested, the subject looked at the dorsal aspect of the model's right hand, and then the little finger lay to the right of the other three fingers. In other words, when the relative positions in space of the four fingers are alone considered, the little finger occupies the relative position on the dorsal aspect of the pronated hand that the index finger occupies on the palmar aspect of the supinated.

After training the palmar set of spots on the right index finger the accuracy of localization of tactile stimuli on the dorsal sets of spots apparently improved for all the fingers. The (apparent) improvement was greatest for the little finger, about equally great for the index finger and ring finger, and least great for the middle finger; but in no case was the improvement comparable to that which occurred in the case of the trained palmar set of spots itself. In that trained set the chief improvement occurred in the localizing of tactile stimuli upon spots "1" and "2." In the case of the dorsal aspect of the little finger the accuracy of localization of tactile stimuli upon spot "1" was worse than before, but that of spot "2" was better. In the case of the dorsal aspect of the right index finger, improvement occurred for both spots "1" and "2," while the accuracy of localization became worse for spot "3." The improvement of spot "1" here is striking, not for its extent but because no such improvement of this spot occurred on the other fingers (save a small and negligible one on the fourth digit). Of the spots "1" on the palmar aspects of the fingers a great improvement occurred on the trained finger, a comparatively small improvement on the fourth digit again, and the localization of stimuli became worse for this spot on the second and fifth digit.

This would almost indicate that there was in fact an improvement

of localization of tactile stimuli applied to the spots on the dorsal aspect of the trained finger—an improvement conditioned by the training of the palmar set of spots. But there was a very significant difference between the two improvements. In the case of the trained set of spots, the improvement in the accuracy of localizing tactile stimuli applied to one of them was accompanied by a decrease in the number of times stimuli which were applied to the others were thought to be located upon that first spot. In other words, where a larger proportion of the stimuli applied to spot "1" were localized by the subject upon spot "1," a smaller proportion of the stimuli applied to spots "2" and "3" were localized by the subject upon spot "1." When the sets of spots on the untrained fingers were examined after training the right index finger, this did not obtain. For we then found that (with few exceptions) where improvement in the accuracy of localization of tactile stimuli occurred for a certain spot on a certain (untrained) finger, there occurred also an increase in the number of times stimuli applied to the remaining two spots on that finger were wrongly localized upon that certain spot. This relationship of the increase of accuracy in localizing stimuli applied to a spot and the increase in the error of localizing upon it stimuli applied to the other two spots was well marked in the case of the dorsal sets of spots on the right index and little fingers. In other words, whereas in the trained palmar set of spots on the right index finger increase in the accuracy of localizing tactile stimuli applied to spot "1" was accompanied by decrease in the error of localizing upon it stimuli applied to spots "2" and "3": in the untrained dorsal set of spots on that finger increase in the accuracy of localizing tactile stimuli upon spot "1" was accompanied by increase in the error of localizing upon spot "1" stimuli applied to spots "2" and "3."

We are, therefore, most probably justified in assuming that, whereas the great improvement in the localizing tactile stimuli upon the trained spots themselves is referable to the training, the smaller (apparent) improvement for the corresponding untrained spots on the dorsal aspect of the trained finger is not referable to that training, but is conditioned by some more general process. To the consideration of that general improvement we shall return later.

Thus far we have considered various facts which seem to point to the relative independence of the factors which condition the accurate localization of tactile stimuli applied to different spots on the skin, and before passing on we may notice some other phenomena which seem to point to the same conclusion.

There are two kinds of error in localization which may possibly be related to different elements in the process. Of these the first is the tendency to localize upon different spots stimuli which actually are applied consecutively to the same spot on the finger; and the second is the tendency to localize upon one and the same spot stimuli which actually are applied to different spots. The first type of error may be associated with defect in the element of "individuality" in the localization; and the second type may be associated with defect in the element of "character." In investigating these errors various relationships may be examined. For in the first place there may be a relation between the degrees of the two errors in any one finger at any one examination—that is, both errors might constantly be great or both might be small; or the relations between the two might be a reciprocal one, one being small when the other is great—or there may be no constant relation. And, in the second place, if improvement in one or both of these errors is one of the conditions of the improvement of the localization of tactile stimuli applied to the trained set of spots, another relationship may be investigated when the incidences of these errors are examined in the cases of the spots on the untrained fingers—that is, it is possible that a constant relation exists between fall in these types of error in the trained spots and fall in the untrained ones, or that no such relation exists.

There appears to be no constant relationship between the incidences of these two types of error in any one set of spots at any one examination. Sometimes the proportions of the two types of error may both be high; at other times they may both be low; at yet other times one may be low and the other high.

As the one type of error denotes defect in the element of "character" and the other denotes defect in the element of "individuality," this seems to indicate, as far as these present results go, that impairment of the element of "character" in the localization of tactile stimuli which are applied to different spots is not necessarily related, either directly or inversely, with impairment of the element of "individuality."

When we examine the incidences of the different types of error after the training of the palmar set of spots on the right index finger, we found that in the first place there was a marked fall in the error wherein the subject localized two consecutive similarly located stimuli upon two different spots. There was also a fall in the number of series of consecutive similar localizations which the subject made to dissimilarly located stimuli—although the fall was slight if analysed only in

terms of two consecutive similar localizations of stimuli applied to two different spots where the first localization was a correct one. It is probable that the improvement of localization of stimuli applied to the trained set of spots was due to reduction of both these types of error. The first of these two types of error may be termed here "individuality-error," and the second "character-error."

The decline in the incidence of individuality-error for the palmar set of spots on the right index finger was accompanied by an even greater decline for the dorsal (untrained) set of spots on the same finger. This would seem to indicate a relationship between the two sets of spots—so that the training of one of them conditioned an improvement in the localization of tactile stimuli which were applied to the other set. But in the case of the palmar and dorsal sets of spots on the right little finger a great decrease in the incidence of this type of error occurred for one set and an equally great increase in the incidence of this error occurred for the other set. This would hardly be the case if such a relationship between the two sets of spots on a finger existed, and we are perhaps correct in supposing that the training of the palmar set of spots on the right index finger was not the condition of the improvement in this type of error in the case of the dorsal set of spots on the same finger—but no positive conclusion can be drawn.

The individuality-error shows its greatest decline in incidence in the cases of the three sets of spots, the localization of stimuli applied to which showed the greatest improvement (trained palmar spots of right index finger, untrained dorsal sets of spots of index and little fingers), but there is no constant relation between the degree of improvement of localization and degree of fall of this error. The degrees of improvement of localization in the records after training the right index finger were very similar in four of the sets of untrained spots (these degrees may be denoted by the figures 2·3, 3·7, 2·4, and 2·0), but the corresponding degrees of change of the individuality-error showed marked variation (these degrees may be denoted by the figures −1·2, −8·0, +29·8, and +7·9).

After the training of the palmar set of spots on the right index finger there is therefore no constant relationship between the changes in the incidence of the individuality-error; and it may perhaps be inferred that, if the fall in the incidence of that error in the trained set of spots was conditioned by the training, that training conditioned no corresponding fall in the case of the untrained sets of spots.

Our figures for the character-error are not so definite, but in this

case also—as far as the figures go—no constant relationship between improvement in the trained spots and change in the incidence of error in the untrained ones can be drawn.

Another curious absence of relationship occurred in these experiments. After the training of the palmar set of spots on the right index finger the subject greatly improved in his localizations of tactile stimuli which were applied to them when he knew that the stimuli were being applied to these spots and to them alone. It might have been supposed that along with this improvement there would have been an improvement in the accuracy of his localization of stimuli applied to them when the stimuli were not restricted to that finger. That is to say, that when the stimuli were applied to other spots as well as to the trained ones, it would have been expected that at any rate the subject would point to the right index finger each time it was touched. We actually found that in such unrestricted tests, after the training the subject indicated the right index finger less often correctly than before the training. The test of course was not completely unrestricted, it was restricted to twelve spots—three on the palmar aspect of each finger of the right hand. We term it "unrestricted" (meaning "comparatively unrestricted") because it was not restricted to the spots on a single finger.

The inference from this is, that in the improvement of the localization of tactile stimuli applied to the trained set of spots on the right index finger, improvement of the element of "finger" in the "position" was not one of the factors.

So far, therefore, it would seem that the improvement in the localization of tactile stimuli applied to the trained spots is not only restricted to that set of spots, but that it is a special and independent process for each of the trained spots. We must now refer to the results of one test which seem to contradict this.

When the subject localized stimuli applied to the ordinary spots on the palmar surfaces of the four right fingers without knowing to which spot or to which finger the stimulus was applied, it was found that the accuracy of localizing the spots (without taking account of the accuracy of localizing the finger on which they lay) was much greater than it was expected it would be. We had thought it possible that the proportion of correct replies to this part of the questions put to the subject would approximate to the average of the proportions for the spots on the four fingers when these were tested separately in the ordinary test—where the subject knew to which finger the stimuli were being applied. We thus expected that, where the localization for the

spots of one finger was very inaccurate, and where it was comparatively accurate for the spots of another finger, as these spots were equally often touched in the unrestricted finger test the accuracy of localization there would be the mean of the accuracies for the separate fingers in restricted finger test. Indeed it might have been expected to be less if hazard came into the localization; for the hazard error in the test of a single finger is 66·7 per cent., whereas in the unrestricted finger test it is 91·7 per cent. As a matter of fact, we found that this error was much less than the average of the errors for all the fingers in the restricted test, and that actually it approximated, both before and after training, most closely to the error of the most accurately localized set of spots in the restricted test.

This result (which in this case was most striking, but which we have not obtained in another similar case) was quite an unexpected one. After the training of the palmar set of spots on the right index finger that was the most accurately localized set, and the average error of localization fell most markedly for it. In the unrestricted test there was a corresponding increase in the accuracy of localization of the spots touched as regards the place on the finger (that is, as regards the position of the spot in the set) and irrespective of the accuracy of localizing the finger.

The inference from this would seem to be that as regards this specific case, the training of one set of spots was accompanied by an improvement of the element "place on finger" in the localization of tactile stimuli which were applied to them and that this improvement extended to other and untrained spots, but only (or only markedly) when the test was not restricted to a single finger.

It is not difficult to see how such a general improvement may have occurred. The three spots on each finger occupied similar positions relatively to the parts of the finger—one spot lay in the middle of each obvious part or segment of the finger. The training of the spots of one set no doubt improved the subject's schema of their positions; it improved, as it were, the element "place on finger" in the "positions" of the touches. But that element is common to the spots of the untrained sets, and its improvement for one set may well have conditioned improvement for other and untrained sets of spots. The difficulty is to see how, in this case and at this period in the experiment, the improvement occurred only when the test was one unrestricted as regards the fingers to which the tactile stimuli were applied—but restricted to the three spots on each finger.

The occurrence of "positive error" in the localization of the finger (apart from the localization of the place of the spot on the finger) in this test gives us a hint as to the reason for this curious restriction of the improvement. In the unrestricted test it was found that the subject more often localized the tactile stimuli upon certain fingers than upon others, and that the error in localizing finger alone was in some cases considerably greater than the error of hazard. In other words the subject had a definite bias against the localization of stimuli upon certain fingers. The restriction of the test to a single finger (when that was done) no doubt brought in a complicating factor; for the subject knew that the tactile stimuli were applied to a certain finger, and might yet feel that the touches were on another finger. In making his decision, for instance, of the localization of a touch applied to spot "2" on a certain finger, he might think that the touch (which felt, for example, as if it was on spot "2" of another finger) most resembled one applied to spot "3" on the finger to which he knew that the stimuli were being applied. Thus he might make an incorrect localization of the place of the touch upon the finger, although—had the test been unrestricted as regards the fingers—he would have placed the touch in the correct position upon the finger, but on the wrong finger. It is therefore possible that in the unrestricted finger test a complication was removed, and this common element of "place on finger" in the "position" of the touches was so freed that the improvement in it conditioned by the training of one set of spots was extended to others.

We may now consider the nature of the improvement of localization of tactile stimuli which followed the training of the spots on the palmar aspect of the right index finger. That improvement occurred not only in the case of the trained set of spots, but also in the case of some of the sets of spots on the untrained fingers.

In the case of the trained set of spots the records show a decrease both in the character-error and in the individuality-error after the training. Thus, after that training, when tactile stimuli were applied to the three spots in such an order that no two consecutive stimuli were applied to the same spot, on the whole there were fewer consecutive similar answers given—on fewer occasions after the training were consecutive dissimilar stimuli localized by the subject upon the same spot on the model. At the same time, when tactile stimuli were applied to the three spots in such a manner that two or more consecutive stimuli were given to the same spot, there were, upon the whole, fewer consecutive dissimilar answers.

But in our results there was also a reduction in one of the position-errors. The abolition of the character-error—so that the subject was always able to say correctly whether or not a certain tactile stimulus was applied to that same spot on the skin to which an immediately preceding stimulus had just been applied—if unaccompanied by improvement in the other factors in localization would easily be recognized in the records. For where series of tactile stimuli were given so that no consecutive two were applied to the same spot, the answers would also show series in which no consecutive two answers were similar, but tactile stimuli applied at different times to any one spot would be localized now upon one spot of the three, and now upon another. The error in the localization of tactile stimuli applied to a certain spot of the three would be the error of hazard—66·7 per cent., and of the answers to these stimuli 33·3 per cent. would be localizations on each of the two possible wrong positions. If, however, there was also abolition of the individuality-error the errors of localization would be expected to become constant. Stimuli applied to spot "3" might thus always be localized upon spot "2," and so on. In such a case the error of localization of stimuli applied to a certain spot in a series of records would be the error of hazard if the individuality of the tactile stimuli applied to that spot varied from day to day. In any case the answer to stimuli applied to a spot would be expected to be constant for any one record, and the average error for all the spots tested would be expected to be the error of hazard.

Our records give no approximation in error to the error of hazard after the training of the spots. The inference is that along with the reduction of the character-error and the individuality-error there is a reduction of the position-error. As reduction of the character-error occurred to an even greater extent in the case of certain of the untrained sets of spots; and as reduction of the individuality-error occurred to an even greater extent in the case of certain other sets of untrained spots; but, as, nevertheless, the reduction of the total error of localization of the untrained sets of spots was in no case comparable with the reduction of this error in the case of the trained set of spots, we are inclined to think that the improvement in the localization of tactile stimuli applied to the trained spots was chiefly due to improvement in the element of "position."

Improvement in the localization of stimuli which are applied to a certain spot would be expected to have a reverse as well as an obverse side. In the first place, stimuli applied to that spot are less often

localized by the subject upon other spots: and in the second place, stimuli applied to other spots would be expected to be less often localized by the subject upon the spot. If the character and the individuality of stimuli applied to the spots are alike improved, and if at the same time there is an improvement in the position—in the correct placing upon the finger—of each of these stimuli, the stimuli applied to a certain spot will less often be localized upon another, and the stimuli applied to the other spots less often upon the first.

Of the three trained spots, spot "1" showed a very definite improvement in the localization of tactile stimuli which were applied to it. They were always correctly localized after the training—so that the error of localizing upon the other two spots touches which were applied to spot "1" fell to zero. At the same time there was a reduction of the errors of localizing stimuli applied to either of the other two spots upon this spot. After the training spot "2" showed also a great improvement in the localization of tactile stimuli applied to it. The error of localizing touches of this spot upon either of the other two spots ("1" and "3") fell considerably; but, while there was a reduction of the error of localizing touches of spot "1" upon this spot (a reduction to zero), there was actually a small increase of the error of localizing touches of spot "3" upon it. Spot "3" itself showed a comparatively small improvement in the localization of tactile stimuli applied to it. The error of localizing touches of this spot upon spot "1" fell slightly (the reduction being much less than that of the error of localizing touches of spot "2" upon spot "1"), but the error of localizing touches of spot "3" upon spot "2" actually rose slightly. The errors of localizing touches of spot "1" and "2" upon this spot "3" showed, as we have said above, great reductions.

From these differences in the improvement of the accuracy of localization of tactile stimuli upon spots "1" and "2," on the one hand, and spot "3" upon the other, it may perhaps be inferred that the training comparatively failed in the case of the last, and that the slight improvement was due to some other process than that which occurred in the two former. Again it must seem as if the obverse and the reverse of the improvement in the localization of tactile stimuli which are applied to a trained spot are not interdependent. Thus a great improvement in the localization of tactile stimuli which are applied to a certain spot (spot "2") is accompanied by a decrease in the error of localizing these stimuli upon a certain other spot (spot "3"), but there is no corresponding decrease (and indeed there is actually an increase) in the error of

localizing tactile stimuli which are applied to that certain other spot ("3") upon the first spot ("2"). The subject as it were recognizes more clearly touches which are applied to a certain spot, but this more clear recognition does not necessarily help him to realize that touches which are applied to another spot are not applied to the first spot. In other words the improvement of localization of tactile stimuli which are applied to a certain spot is not necessarily accompanied by a corresponding improvement for other spots on the same aspect of the same finger. It would appear as if each spot is improved for itself without reference to the others. Where the improvement occurs in two spots there is a mutual relationship—"obverse" and "reverse"—in the reduction of the errors of localization of the two; but where only one of a pair of spots shows a great improvement no such mutual relationship may occur.

In addition to the special improvement in the localization of tactile stimuli which occurred in the case of the trained spots, there occurred a less marked general (apparent) improvement in localization for the untrained sets of spots on the other fingers—and on the dorsal aspects of all the fingers. In what did this consist?

A most marked change which synchronized with the period of training was the disappearance of error due to "confusion." Before the training the subject repeatedly indicated that he was unable to come to a decision with regard to the localization of certain stimuli. After the training, on scarce an occasion did he fail to make a localization of some sort, and the disappearance of this source of error was a general one—it extended to stimuli applied to the untrained as well as to the trained sets of spots. It is clear that even if the subject had hazarded his localizations of the touches of which he was not certain, this would have led to a reduction of the percentage error of localization—for a certain proportion of these touches would then have been bound to be correct. If, however, we speculate that the "confused" touches were (after the disappearance of the "confusion" error from the records) really localized in the same proportion (as between "right" and "wrong") as the definitely localized touches before the disappearance of the "confusion" error; and, having found the proportion of the "confused" answers which corresponds with the proportion of wrong definite localizations before the disappearance of "confusion," we then add the two together, it is found that the resultant corresponds very definitely with the proportion of definite wrong localizations made in the records after the disappearance of the "confusion" error as far as the untrained sets of spots are concerned. This is demonstrated in Table

XXXIII. It is there seen that except in the case of the trained set of spots on the palmar aspect of the right index finger the percentage error of localization for the untrained sets of spots (after the disappearance of the "confusion" error) is very nearly what it would have been had the same proportion of the previously "confused" touches, as of the previously definitely localized touches, been wrongly localized. In the localization of touches on the palmar sets of spots the actual error is slightly greater than it would have been if this had been exactly the case; a yet closer approximation occurs in the case of the dorsal sets of spots, but only in the case of the dorsal set of spots on the little finger ("R 5") is the actual error less than the computed.

It will be remembered that there was some evidence to show that in the case of one of the trained spots the improvement of localization was probably not very largely conditioned by the training—spot "3." In Table XXXIII the figures for the three individual spots of the trained set are also given. It is seen that in the case of spots "1" and "2" the actual error of localization after the training (and after the disappearance of the "confusion" error) is very much less than it would have been if the decline in error had been due solely to the correct localization of a proportion of the touches which before had been "confused." But in the case of spot "3" we again obtain a close approximation between the actual error and the error computed as above (that is, by adding to the proportion of definitely wrongly localized touches before the training the corresponding proportion of the un-localized or "confused" touches). Here, however, the actual error is slightly less than the computed.

This all seems to point to the fact that the apparent improvement in the localization of tactile stimuli upon the untrained spots (and upon one of the trained ones) is really due to the disappearance of the "confusion" error—that it is not a real general improvement. The figures throw into an extremely strong light the great change which took place in the case of two of the trained spots—a change which we think can be ascribed to the training. We think that the apparent improvement in the cases of the untrained sets of spots is, at this stage in the experiment, not a real one; but we say this with the knowledge that later a real improvement occurred.

This seems to dispose of the question of the apparent general improvement in localization of touches applied to the untrained sets of spots, but certain changes took place in the incidence of error amongst them after the training of the right index finger—and these changes are of interest. In some cases the proportions of correct localizations for

the touches applied to the individual spots on the untrained fingers showed differences in the records before and after the training of the palmar set of spots on the right index finger. But, whereas in the case of the trained spots the increase in the proportion of correct answers for a spot was, on the whole, accompanied by decrease in the wrong localizations upon it of touches applied to other spots, in the case of the untrained spots a rise in the proportion of correct localizations for a certain spot was almost always accompanied by a rise in the proportion of times touches applied to other spots were localized upon it. This really means that, after the training, the subject was more apt to place any tactile stimulus upon a certain spot than before it. Thus in the cases of the dorsal sets of spots there was a greater tendency to give the answer spot "2" (whether it was right or wrong) after the training than before it. The increase in the proportion of times spot "2" was given as an answer (which was accompanied by an increase in the proportion of correct localizations of touches applied to that spot) was accompanied by a decrease in the proportion of answers spot "1," and by a decrease in the proportion of answers spot "3." It occurred, as it were, at the expense of the answers spot "1" and spot "3," and at the expense of the answer "confused." Here we have a definite tendency to a certain localization—which would not be expected to be the case had the answers merely been selected by hazard.

In connection with this definite change in the numerical proportion of the different answers to the touches it must, however, be noticed that both before and after the training of the right index finger there was a greater tendency to make the wrong localizations of touches of spot "1" upon spot "2" than upon spot "3"; and a corresponding greater tendency to make the wrong localizations of touches of spot "3" upon spot "2" than upon spot "1." That is to say, that when one of the terminal spots of the set of three was wrongly localized it was more often referred to the middle spot—that nearest to it—than to the spot at the other end of the set. Had a general improvement occurred in the localization of touches upon the untrained spots it might have been expected that, along with a greater proportion of correct answers to touches upon each of the terminal spots of the sets, there would have been a reduction of the incorrect references to the spot at the other end of the set and an increase in the incorrect references to the middle spot—as it were, a partial improvement in the accuracy of localization. Had this occurred the number of answers spot "2" both to touches

applied to that spot itself and to touches applied to the spots at the two ends of the set (spots "1 and 3") would have increased. But as a matter of fact the increase in the number of answers spot "2" in the case of the untrained dorsal sets of spots increased along with a decrease in the correct localizations of touches applied either to spot "1" or spot "3" or both to the touches applied to these two spots. We are, therefore, justified in the assumption that the increase in the number of answers spot "2" in the case of tactile stimuli applied to these untrained sets of spots was not due to a partial general improvement of localization, but to a definite tendency to refer the touches rather to that spot than to the others—an approximation to "positive error."

On the whole, then, we may say that proper analysis seems to eliminate the occurrence of a general improvement of the localization of tactile stimuli which were applied to the untrained sets of spots (and perhaps also to one of the trained spots): and that it seems to show that the improvement in the case of two of the trained spots was due either to the effect of the training or to some other change which did not affect the untrained sets of spots.

It is thus possible that the conditions of the experiment more favoured the accuracy of localization of touches upon the set of spots which we selected for training than that of the touches upon the untrained sets of spots; and it is also possible that the conditions of the cortical (or cerebral) lesion were not stable, and that by chance the change effected an increase of the accuracy of localization for the trained spots only.

Thus, in the first place, we investigated the fingers in a constant order. First, the palmar surfaces of two of the normal fingers were tested; then, in order, the palmar surfaces of the four affected fingers—beginning with the right index finger; then the dorsal surfaces of two of the normal fingers; and finally the dorsal surfaces of the four affected fingers—again commencing with the right index finger.

It is thus possible that a process of "general fatigue" may have so complicated the results that the fingers first tested may have appeared more accurate in localization than those last tested. But our records give little indication that this was the case. In the first place the records before the training of the right index finger should then have shown the same progressive changes as those taken after it. This is not the case. The first affected finger to be tested shows then greater inaccuracy than the second: the third than the fourth. In the second place the different fingers might have been expected to show a definite

descending order of improvement of localization in the order in which they were tested. This, again, is not the case. Thirdly, in this part of the experiment we constantly used as a control one of the normal fingers, testing the accuracy of localization of tactile stimuli upon it at the end of the record, when general fatigue would be expected to be at its maximum. The accuracy was seldom found to be less than at the commencement of the test. Fourthly, on one occasion we repeated the test of the right index finger at the end of the record, and the accuracy of localization was then found to be greater than before. On the whole, we may say that, although there probably was some process of general fatigue, it cannot be regarded as the explanation of our results.

But we cannot, on the evidence furnished by this part of the experiment alone, eliminate the possibility that the improvement of the localization of tactile stimuli applied to the trained spots may have been due to some change in the condition of the central lesion—a change associated only by chance with the training of the spots. We think, however, that this possibility must be eliminated in view of the data we obtained in subsequent parts of the experiment. For, later on in it we selected another finger—the fourth right digit—and found that improvement in the localization of tactile stimuli applied to its palmar set of spots also occurred during and after training. As the error of localization of tactile stimuli upon the spots of this finger was large before that training—as it was, indeed, larger than that of any other set of spots in this first part of the experiment—and, as after the training, it became only less small than the error in the case of the finger which we first trained, we think that this disposes of the possibility that the results which we have described here were due to a change not connected with the training. We do not claim, however, that no such change, or that no general improvement in the localization of tactile stimuli occurred throughout the whole course of the experiment.

V.—Analysis of the First Series of Tests, during which an Attempt to educate Spots in Accuracy of Localization of Tactile Stimuli was made.

(1) *In General.*

In this series of tests two sets of three different spots were selected for examination in each of the second, third, fourth, and fifth digits of the affected right hand, and on the third and fourth digits of the

"normal" left hand. Of these two sets, in each case one lay on the palmar aspect and one on the dorsal; the three spots of each set lay on the skin of the finger in its dorsi-ventral axial plane, one being opposite the mid-point of each of the three phalanges. For the purposes of a small number of tests, a third set of three spots was chosen on the palmar aspects of each of the four fingers of the right hand. These also lay on the skin in the dorsi-ventral axial plane of the finger, but they were placed on the folds of skin at which the finger bends, and which lie near to the metacarpal-phalangeal and the two interphalangeal joints.

In the records care had not been taken to assure that each spot on a finger in the test was stimulated the same number of times, and the number of times a specific spot was stimulated in different records varied. As the experiment proceeded, we found that the accuracy of localization of tactile stimuli was not the same for the three different spots on a finger—it was, for instance, sometimes most defective for spot "3" (that nearest the trunk) and least defective for spot "1" (that nearest the tip of the finger). It is thus clear that a record in which spot "1" is stimulated more often than spots "2" or "3" may give a different percentage of error than one in which spot "3" is most often stimulated. In estimating the error of localization in a record in this series of observations, we have, therefore, used the "average percentage error" which is obtained by finding the "percentage error" for each of the three individual spots, and taking the average of the three percentages. As there was not, however, a large preponderance of the times any one individual spot was stimulated in any one record, this does not markedly differ from the percentage error of the record; the difference between the percentage error and the "average percentage error" in the records is usually less than 1 per cent., and rarely greater than 2 per cent.

(2) *On the Records which were taken before Training commenced.*

For the first to the fifth day of the series the tests were applied in the ordinary manner to the spots on the palmar and dorsal aspects of the fingers. The following table, in which L 3 and L 4 stand for the digits of the left hand, and R 2, R 3, &c., for those of the affected right hand, gives the "average percentage error" of localization for the spots on the palmar and dorsal aspects of the different fingers on the five different days—twenty-five stimuli applied in an indiscriminate order being given to the three spots on each aspect of each of the fingers which were tested:—

TABLE I.—"Average Error per cent." for Localization of Tactile Stimuli on the Palmar and Dorsal Sets of Spots of each Finger on each of the Five Days which immediately preceded the attempt to Train the Palmar Spots on the Right Index Finger. Each Figure is Calculated from Twenty-five Answers—except the Averages and Mean Variations in the Right-hand Columns.

	Day of Experiment						
Finger	1	2	3	4	5	Average	Mean variation
Palmar L 3	7·4	0·0	0·0	0·0	0·0	= 1·48	2·37
L 4	0·0	0·0	14·3	0·0	8·3	= 4·52	5·42
R 2	35·4	41·8	50·9	44·0	41·4	= 42·70	3·80
R 3	31·7	17·6	38·7	25·9	46·0	= 31·98	8·30
R 4	39·0	40·0	46·8	47·3	61·1	= 46·72	5·96
R 5	46·0	44·0	33·3	36·9	55·1	= 43·06	6·37
Dorsal L 3	0·0	0·0	0·0	0·0	3·3	= 0·66	1·06
L 4	4·3	3·3	0·0	2·6	0·0	= 2·04	1·63
R 2	25·4	30·7	20·4	44·4	21·9	= 28·56	7·19
R 3	19·0	11·4	20·9	21·7	20·8	= 18·76	2·94
R 4	43·5	15·0	17·6	26·9	31·0	= 26·80	8·40
R 5	27·0	27·8	20·0	53·1	35·2	= 32·62	9·22

It will be observed that for their palmar aspects the arrangement of the right digits in order of decreasing accuracy of localization of tactile stimuli is: R 3, R 2, R 5, R 4; the corresponding order for the dorsal aspects is: R 3, R 4, R 2, R 5; and the most accurate finger for either aspect is R 3.

The second table gives the average percentage error for each individual spot on each finger in this same series of records:—

TABLE II.—The Total Percentage Error of Localization for each of Spots "1," "2," and "3" on the Palmar and Dorsal Aspects of each of the Fingers examined on the Five Days which immediately preceded the Training. Each Percentage is Calculated from about Forty-two Observations.

	Number of Individual Spot.		
Finger	1	2	3
Palmar L 3	0·00	2·17	2·63
L 4	0·00	0·00	15·38
R 2	32·43	62·50	35·00
R 3	13·33	26·32	59·52
R 4	25·71	31·37	79·49
R 5	37·78	46·67	40·00
Dorsal L 3	2·38	0·00	0·00
L 4	4·65	1·82	0·00
R 2	45·95	25·00	15·00
R 3	15·56	34·21	9·52
R 4	31·43	33·33	20·51
R 5	37·78	40·00	17·14

It will be observed that in the case of fingers R 3, R 4, the accuracy of the localization of tactile stimuli on spot "3" (that nearest the

trunk) on the palmar aspect is markedly less than that on spots "1" and "2"; while the accuracy of the localization on spot "1" is markedly greater than that on spot "2." In the case of the other two fingers (palmar aspects) the accuracy of localization of tactile stimuli is worst for spot "2," and about equal on spots "1" and "3." When the figures for the dorsal aspects of the right digits are examined, it is seen that in every case the accuracy of localization is least defective on spot "3" (that nearest the trunk), and, except in the case of R 2, most defective on spot "2."

The average percentage error for the localization of tactile stimuli on spot "3" of the palmar aspect of the fourth right digit—R 4—is a figure of interest. That percentage is 79·49—markedly greater than the error of hazard, which is here 66·67 per cent. The following table expands this figure :—

TABLE III.—PERCENTAGE ERROR OF LOCALIZATION FOR SPOT "3" ON THE PALMAR ASPECT OF THE FOURTH RIGHT DIGIT, "A" IN EACH OF THE FIVE RECORDS BEFORE, AND "B" IN EACH OF THE FIVE RECORDS AFTER, "TRAINING" THE SECOND RIGHT DIGIT.

Record	A	Record	B
1	62·50	9	100·00
2	75·00	10	50·00
3	100·00	11	54·55
4	90·91	12	66·67
5	75·00	13	77·78

It will be seen that on only one occasion—the first—was the average error for this spot less than that of hazard. This is an instance of "positive" error in localization. It is markedly greater than the error which would occur if the subject had no idea which of the three spots was touched, and indicated any one of them indiscriminately by chance.

The kind of answer which was given in these cases to a tactile stimulus which was applied to spot "3" is of interest. Each time the spot was touched the subject gave one of four possible answers with regard to its localization. In the first place the answer might be correct, and the subject then indicated correctly the corresponding spot on the hand of the model. In the second place the subject might be unable to make a localization (he then tapped the table). While in the third and fourth places the subject might make a wrong localization—indicating either spot "1" or spot "2" on the model as that corresponding to the spot touched. The following table gives the average number of times per cent. each of these answers was given :—

TABLE IV.—Analysis of the kind of Answers given when Spot "3" on the Palmar Aspect of the Right Fourth Digit was touched in the Records detailed in Table IV, giving Total Numbers and Percentages for the Two Sets of Records, "A" and "B."

Answer	A (Records 1 to 5) No.	Per cent.	B (Records 9 to 13) No.	Per cent.
Right—i.e., "3"	8	20·51	14	30·43
Confused	4	10·25	0	0·00
"1" instead of "3"	1	2·56	2	4·35
"2" instead of "3"	26	66·67	30	65·22
	39	99·99	46	100·00

Had they been selected by hazard the percentage in each case would have been about 25·00; as it is, it is seen that the wrong answer "2" for "3" is given in two-thirds of the cases. The positive error in the localization of tactile stimuli applied to spot "3" on the subject is, therefore, very largely conditioned by his mistaking the locus of the stimulus for that of stimuli applied to spot "2."

The number of times "confusion" occurred in the record for the palmar and for the dorsal set of spots of each finger on each of the first five days is given in the table below. The total number of stimulations in each case was 25 for the set of palmar spots, and the same number for the dorsal:—

TABLE V.—The number of times (out of Twenty-five Observations in each case) no Localization could be made—"Confusion"—for each of the Palmar and Dorsal Sets of Spots of each Finger on each of the Five Days which immediately preceded the Training.

	Finger	Day of Experiment 1	2	3	4	5
Palmar	L 3	0	0	0	0	0
	L 4	0	0	0	0	0
	R 2	0	2	3	6	8
	R 3	0	0	2	0	5
	R 4	0	1	3	4	5
	R 5	0	0	3	3	4
Dorsal	L 3	0	0	0	0	0
	L 4	0	0	0	0	0
	R 2	0	1	2	8	3
	R 3	0	1	2	2	6
	R 4	0	2	1	3	5
	R 5	0	1	2	7	6

The apparent absence of "confusion" on the first day is due to the fact that the subject did not clearly realize that he was to tap the table when he was unable to make a localization; on this day it is probable that a certain number of his answers were guesses. We think that

this is the only occasion in the experiments on which he guessed an answer.

A remarkable feature of the early experiments was that on the one hand the subject repeatedly localized successive differently located tactile stimuli on the same spot, and that, on the other hand, he repeatedly localized successive similarly located tactile stimuli on different spots.

It is difficult to make an analysis of these types of error. It may be attempted by scrutinizing the answers to consecutive similar pairs of tactile stimuli, but this makes no account of instances in which different replies are given in series of similar stimuli; or in which the same reply is made many times in succession when different spots are touched. We have observed a marked tendency for a series of similar replies to be given to a series of different tactile stimuli; and when a series of similar stimuli has been given there is a tendency for the type of reply to persist, and for the subject thus wrongly to localize a dissimilar stimulus which is applied immediately after the series.

In the following table the number of times two different answers were given to two consecutive similar stimuli is given as a percentage of the number of times pairs of similar stimuli were given in a test—these percentages being given for the dorsal and palmar sets of spots on each finger on the first five days of the experiment:—

TABLE VI.—THE PERCENTAGE NUMBER OF TIMES PAIRS OF TWO CONSECUTIVELY SIMILARLY LOCATED STIMULI WERE LOCALIZED ON TWO DIFFERENT SPOTS; GIVEN FOR EACH ASPECT OF EACH FINGER ON EACH OF THE FIVE DAYS WHICH IMMEDIATELY PRECEDED THE TRAINING.

		Day of Experiment.						
	Finger	1	2	3	4	5	Average 8·0	Mean variation
Palmar	L 3	40·0	0·0	0·0	0·0	0·0	= 8·0	12·8
	L 4	0·0	0·0	25·0	0·0	0·0	= 5·0	8·0
	R 2	50·0	20·0	20·0	60·0	50·0	= 40·0	16·0
	R 3	40·0	0·0	50·0	20·0	62·5	= 34·5	19·6
	R 4	33·3	50·0	25·0	33·3	20·0	= 32·3	7·9
	R 5	16·7	11·1	28·6	25·0	60·0	= 28·3	12·8
Dorsal	L 3	0·0	0·0	0·0	0·0	14·3	= 2·9	4·6
	L 4	12·5	0·0	0·0	25·0	0·0	= 7·5	9·0
	R 2	25·0	60·0	20·0	60·0	25·0	= 38·0	17·6
	R 3	0·0	25·0	16·7	40·0	37·5	= 23·8	12.4
	R 4	33·3	0·0	37·5	16·7	40·0	= 25·5	13·7
	R 5	0·0	44·4	57.1	100·0	40·0	= 48·3	24·2

In Table VII the number of times two consecutive stimuli applied to different spots were localized by the subject upon the same spot is given for each record on each of the first five days of the experiment. In

each record of 25 successive tactile stimuli there were about twenty occasions in which two successive stimuli were applied to different spots on the subject :—

TABLE VII.—The number of times Two Different Consecutive Stimuli were Localized upon the Same Spot—given for the Palmar and Dorsal Sets of Spots of each Finger on each of the Five Days which immediately preceded the Training.

Finger	Day of Experiment 1	2	3	4	5	Average	Mean variation
Palmar L 3	0	0	0	0	0	= 0·0	0·0
L 4	0	0	2	0	2	= 0·8	0·96
R 2	8	9	5	1	4	= 5·4	2·5
R 3	6	5	3	7	3	= 4·8	1·4
R 4	6	10	2	4	6	= 5·6	2·1
R 5	8	4	5	8	9	= 6·8	1·8
Dorsal L 3	0	0	0	0	0	= 0·0	0·0
L 4	1	2	0	1	0	= 0·8	0·6
R 2	5	4	3	4	3	= 3·8	0·6
R 3	5	2	6	4	0	= 3·4	1·9
R 4	8	3	4	3	3	= 4·2	1·5
R 5	6	5	4	5	2	= 4·4	1·1

The variation of the results here is in part due to the variation in the number of times in a record the subject was unable to make a localization—as these have not been included in the table.

But, with regard to this type of error, it must be noted that it is of two distinct forms, one of which may be regarded as a more inaccurate type than the other. Thus when two consecutive tactile stimuli are applied to two specific different spots on the skin the subject may localize the first wrongly, but may "correct" his error at the second stimulus (if that happens to be applied to the spot to which the subject had localized the first stimulus). Thus similar replies may be given to two different stimuli. But the error would be one of a different type if the subject correctly localized the first stimulus and then incorrectly localized the second stimulus (applied to another spot) on the same spot as the first. But here also his replies to differently located stimuli would be similar. In other words, when the instances in which the subject replies with the same answer to two consecutive differently located stimuli are examined a distinction should be drawn between those cases in which the first of the two stimuli is correctly localized and those in which the second is. In the following table (VIII) the numbers of occasions on which the subject correctly localized the first of a pair of different stimuli and then located the second stimulus at the same spot as the first are given :—

TABLE VIII.—The number of times the Second of a Pair of Dissimilar Consecutive Stimuli was Wrongly Localized on the Same Spot as that on which the First of the Pair had been Correctly Localized—given for the Palmar and Dorsal Sets of Spots of each Finger on each of the Five Days which immediately preceded the Training. The numbers are out of about Twenty Observations each.

Finger	Day of Experiment 1	2	3	4	5	Average	Mean variation
Palmar L 3	2	0	0	0	0	= 0·4	0·64
L 4	0	0	0	0	1	= 0·2	0·32
R 2	3	3	3	0	3	= 2·4	0·96
R 3	3	3	2	4	2	= 2·8	0·64
R 4	3	6	1	1	2	= 2·6	1·52
R 5	6	3	2	4	3	= 3·6	1·12
Dorsal L 3	0	0	0	0	0	= 0·0	0·00
L 4	1	1	0	1	0	= 0·6	0·48
R 2	2	3	1	3	1	= 2·0	0·80
R 3	3	1	3	2	0	= 1·8	1·04
R 4	3	1	3	2	1	= 2·0	0·80
R 5	3	4	2	3	1	= 2·6	0·88

(3) *On the Records which were taken during the Training.*

On three successive days the spots of the palmar set on the right index finger were trained for the localization of tactile stimuli in the manner described before. Records of the accuracy of localization of tactile stimuli on these spots were taken immediately before and immediately after the training and showed uniformly a slightly greater defect immediately after the training.

TABLE IX.—"Average Error per cent." of Localization of the Spots on the Palmar Aspect of the Right Index Finger Before, immediately After, and then at Hour Intervals after Training.

Time	"Average error per cent."
9.45 a.m.	37·2
10.50 ,,	35·2
"Training."	
11.8 a.m.	46·7
12.3 p.m.	40·6
12.57 ,,	38·9
2 ,,	30·3
3.10 ,,	27·6
4 ,,	32·5
5.3 ,,	20·0
6 ,,	19·3
6.54 ,,	12·2
7·45 ,,	15·4
8·52 ,,	25·0

On the third of these days we gave the training in the morning, and thereafter repeated the test of the accuracy of localization of tactile stimuli on the trained spots after each interval of one hour which elapsed. The percentage error of localization gradually decreased (having been considerably higher immediately after the training) and at its least was about one-third only of the lowest previous error on this finger. Table IX gives these average percentage errors.

But when the spots on the palmar aspects of the other fingers were tested at the end of the day, it was found that improvement of the accuracy of localization of tactile stimuli had occurred in every case. This is shown in Table X:—

TABLE X.—"AVERAGE ERROR PER CENT." OF LOCALIZATION OF THE SPOTS ON THE PALMAR ASPECTS OF EACH OF THE FOUR RIGHT FINGERS BEFORE AND AFTER THE RECORDS GIVEN IN TABLE IX.

	Finger	Before	After
Palmar	L 3	0·0	3·0
	R 2	37·2	25·0
	R 3	42·9	30·1
	R 4	50·0	23·3
	R 5	57·2	41·1

TABLE XI.—"AVERAGE ERROR PER CENT." OF LOCALIZATION OF THE SPOTS ON THE PALMAR ASPECT OF THE RIGHT INDEX FINGER AT DIFFERENT INTERVALS OF TIME THROUGHOUT THE DAY.

Time	Four-hour (9)	Three-hour (10)	Half-hour (12)
10 a.m.	—	15·1	7·6
10.30 ,,	16·7	—	—
11 ,,	—	—	—
11.30 ,,	—	—	23·1
12 m.d.	—	—	27·9
	Dinner.		
12.30 p.m.	—	—	26·1 (Finished dinner)
1 ,,	—	7·2	28·1 (Half pipe)
1.30 ,,	—	—	11·4
2 ,,	—	—	25·8 (Pipe)
2.30 ,,	4·8	—	27·2
3 ,,	—	—	25·0
3.30 ,,	—	—	16·9 (Pipe)
4 ,,	—	7·9	28·6 (Sleeping)
4.30 ,,	—	—	15·9
5 ,,	—	—	36·7
	Tea.		
5.30 ,,	—	—	13·3
6 ,,	—	—	34·5 (Pipe)
6.30 ,,	13·4	—	26·4
7 ,,	—	12·5	34·3

After this training was completed we tested, on different days, the accuracy of the localization of tactile stimuli for the "trained" spots on the palmar aspect of the right index finger at different intervals of time throughout the day. Table XI gives the results obtained on three occasions—the intervals between tests being four hours, three hours, and half hours respectively. It will be seen that there is no marked progressive change in accuracy during the day—except that the answers appear generally to be less accurate in the late evening :—

On the occasion of the half-hourly test the accuracy of localization was tested for the corresponding spots on all four right fingers before and after the experiment. The accuracy seems to be markedly less for the second and third digits after it (Table XII). The accuracy of localization was tested at the same time for the set of "untrained" spots on the palmar aspects of the same fingers (those spots which lay on the folds of skin near the joints). Comparatively little change is seen to occur in the case of the second and third digits: but there is a curious reversal of degree of accuracy in the case of the fourth and fifth :—

TABLE XII.—"AVERAGE ERROR PER CENT." OF LOCALIZATION OF THE SPOTS ON THE PALMAR ASPECTS OF ALL THE FOUR RIGHT DIGITS BEFORE AND AFTER THE RECORDS GIVEN IN THE THIRD COLUMN OF TABLE II.

Finger		Before		After
Palmar L 3	..	13·9	..	0·0
R 2	..	7·6	..	34·3
R 3	..	18·8	..	29·2
R 4	..	43·0	..	47·7
R 5	..	43·9	..	31·7

"AVERAGE ERROR PER CENT." FOR THE "UNTRAINED" SPOTS ON THE PALMAR ASPECTS OF THE SAME FINGERS BEFORE AND AFTER THESE RECORDS.

Finger		Before		After
Palmar L 3	..	18·0	..	4·8
R 2	..	60·0	..	65·3
R 3	..	37·6	..	35·2
R 4	..	28·7	..	55·6
R 5	..	50·8	..	7·6

On the three mornings of the days which immediately followed each of these three trainings the accuracy of localization was tested for the dorsal and palmar sets of spots of all the fingers used in the experiments (Table XIII).

There was a very slight progressive increase in the accuracy of localization of the trained spots of the right index finger; but no regular change in the case of the spots on the back of it, nor in the case of the palmar or dorsal sets of spots on any of the other fingers.

TABLE XIII.—"Average Error per cent." of Localization of the Spots on the Palmar and Dorsal Aspects of each Finger on the Three Days, each of which immediately succeeded a "Training" of the Palmar Set of Spots on the Right Index Finger. Each Figure calculated from Twenty-five Observations.

		Day of Experiment.		
	Finger	6	7	8
Palmar	L 3 ..	8·5 ..	0·0 ..	4·2
	L 4 ..	0·0 ..	0·0 ..	0·0
	R 2 ..	39·7 ..	37·2 ..	32·6
	R 3 ..	46·3 ..	42·9 ..	46·6
	R 4 ..	42·0 ..	50·0 ..	37·0
	R 5 ..	21·1 ..	57·2 ..	27·8
Dorsal	L 3 ..	3·7 ..	0·0 ..	0·0
	L 4 ..	0·0 ..	0·0 ..	0·0
	R 2 ..	28·0 ..	13·1 ..	37·6
	R 3 ..	31·2 ..	3·7 ..	35·4
	R 4 ..	32·9 ..	26·7 ..	32·8
	R 5 ..	18·8 ..	25·6 ..	39·3

(4) *On the Records which were taken during the Five Days which immediately succeeded the first Period of Training.*

The ordinary tests were continued on the five days which immediately followed the first attempted training in this experiment. The general results obtained on these days are given in the following table (XIV), where they are expressed as "average error per cent." :—

TABLE XIV.—"Average Error per cent." for Localization of Tactile Stimuli on the Palmar and Dorsal Sets of Spots of each Finger on each of the Five Days immediately succeeding the First Attempt to Train the Palmar Spots of the Right Index Finger. Each Figure (except the Averages and Mean Variations in the Right-hand Columns) is calculated from Twenty-five Observations—save the Figures for the Palmar Set of Spots on the Trained Right Index Finger, which are calculated from Fifty Observations.

		Day of Experiment.						
	Finger	9	10	11	12	13	Average	Mean variations
Palmar	L 3 ..	0·0 ..	0·0 ..	3·3 ..	13·9 ..	0·0 =	3·44 ..	4·18
	L 4 ..	0·0 ..	0·0 ..	3·7 ..	0·0 ..	3·3 =	1·40 ..	1·68
	R 2 ..	**16·7 ..**	**15·1 ..**	**15·7 ..**	**7·6 ..**	**23·5 =**	**15·72 ..**	**3·50**
	R 3 ..	39·5 ..	6·1 ..	42·7 ..	18·8 ..	41·3 =	29·68 ..	13·78
	R 4 ..	41·8 ..	39·8 ..	42·0 ..	43·0 ..	48·7 =	43·06 ..	2·23
	R 5 ..	52·4 ..	26·1 ..	27·0 ..	43·9 ..	54·0 =	40·68 ..	11·30
Dorsal	L 3 ..	0·0 ..	12·5 ..	8·9 ..	6·6 ..	3·7 =	6·34 ..	3·59
	L 4 ..	0·0 ..	0·0 ..	11·1 ..	16·9 ..	0·0 =	5·60 ..	6·72
	R 2 ..	12·2 ..	35·3 ..	27·3 ..	15·6 ..	17·7 =	21·62 ..	7·74
	R 3 ..	7·5 ..	0·0 ..	14·7 ..	19·4 ..	37·0 =	15·72 ..	9·98
	R 4 ..	15·9 ..	32·4 ..	12·6 ..	7·9 ..	34·4 =	20·64 ..	10·21
	R 5 ..	14·4 ..	28·3 ..	28·0 ..	11·1 ..	29·0 =	22·16 ..	7·53

The differences between these results and the corresponding ones which were taken before the "training" of the palmar spots of the right index finger will be discussed later. We may, however, note here that of the spots on the palmar aspects of the four fingers of the right hand those of the right index finger are now considerably the most accurately localized. In order of decreasing accuracy of localization of tactile stimuli these fingers are now arranged thus: R 2, R 3, R 5, R 4: whereas before the training of the right index finger ("R 2") that order was: R 3, R 2, R 5, R 4. But when the accuracy of localization is examined for the dorsal aspects of the same fingers they are arranged in order of decreasing accuracy of localization thus: R 3, R 4, R 2, R 5; that is, in exactly the same order as before the training.

When the figures for the palmar set of spots on the right index finger ("R 2"—the "trained" finger) are examined it is seen that there is a gradual decrease in average percentage error as the records proceed—except in the case of the test taken on the thirteenth day of the experiment. The conditions on that occasion were perhaps peculiar. The subject had spent a comparatively sleepless night, and on the following day he was too unwell to complete the tests. We have included this thirteenth record in our series, but the fourteenth is excluded as it is not a complete one.

In the next table (XV) the analysis of error of localization is given for the three individual spots in all the five records.

TABLE XV.—The Total Percentage Error of Localization for each of Spots "1," "2," and "3" on the Palmar and Dorsal Aspects of each of the Fingers examined on the Five Days which immediately followed upon the Training of the Palmar Set of Spots on the Right Index Finger. Each Percentage is calculated from about Forty-two Observations, except the Percentages for the Spots on the Palmar Aspect of the Right Index Finger (R_2) which are calculated from about Eighty-three.

		Spot 1	Spot 2	Spot 3
Palmar	L 3	0·00	4·35	6·82
	L 4	0·00	4·55	0·00
	R 2	**0·00**	**20·99**	**26·83**
	R 3	14·29	35·42	40·48
	R 4	15·38	42·50	69·57
	R 5	39·53	41·46	36·59
Dorsal	L 3	8·82	6·12	2·38
	L 4	11·63	4·55	0·00
	R 2	31·03	10·20	23·40
	R 3	25·71	8·33	14·29
	R 4	30·77	20·51	10·64
	R 5	41·86	11·90	7·50

The number of observations from which the percentages are calculated in the case of the spots on the palmar surface of the right index finger ("trained") is double that in the case of the other fingers—i.e., a total of 250 observations for the three palmar spots of the right index finger as against 125 observations for the palmar spots of each of the other fingers, and for each of the dorsal sets of spots on all the fingers.

The most remarkable feature of this table is the entire absence of error of localization in the case of the spot on the palmar aspect of the terminal phalanx of the trained right index finger—that is, spot "1"; and the very great reduction of error in the case of the other two spots on the palmar aspect of that finger, as compared with the records before training. In the case of spot "1" no error of localization occurred at any of seventy-one observations distributed over the five different days. A comparison of this table with Table II is extremely instructive, but will be deferred to a later sub-section of this paper. It may, however, be pointed out here that in the case of the palmar sets of spots on the other three fingers there is a considerable similarity between the results obtained before and after the training. On the whole there is a small decrease in the error of localization of tactile stimuli; but if the order of accuracy is examined for the three palmar spots of each of the third, fourth, and fifth digits, it is found that it is the same before and after the training of the second digit—save only that in the case of the fifth digit, while spot "2" is still the least accurately localized, after the training spot "3" is the most accurately localized, while before it spot "1" was. More variation of the order of accuracy occurs in the case of the spots on the dorsal aspects of the fingers; but it will be observed that here, as before the training of the palmar set of spots on the right index finger, upon the whole spot "1" (that on the terminal phalanx) is the least accurately localized; while spot "3" (that on the basal phalanx) is the most accurately localized—the reverse of the findings in the case of the palmar spots.

It will be remembered that in the case of spot "3" on the palmar aspect of the fourth right digit, the error of localization was found to be greater than that which would have been expected to be given had the answers been selected by hazard. The error of hazard should here be 66·67 per cent.; and it will be seen that the error of localization for that spot on that finger is still greater than the hazard error, but yet not so great as before the training of the second digit. It is a matter of interest to examine this error again, and to compare it with the error for the same spot in the first series of records.

In Table III—column B—the percentages of error of localization for this spot on each of the five records taken after the training of the right index finger are given. And on Table IV—column B—there is an analysis of the total number of answers given for this spot in these records. When columns A and B are compared in that Table IV, it is seen that after the training (column B) the percentage of right localizations of that spot is about half as great again as the percentage before the training of the right index finger. On the other hand, the percentages for the wrong answers spot "1" and spot "2" are almost exactly the same as before. The increase in the number of right answers after the training of the other finger seems to have occurred at the expense of the "confused" answers which were given before the training. In other words, the subject now never says that he is unable to localize a tactile stimulus applied to this spot; but when he makes a wrong localization the percentage error for the wrong answer is the same as before. In this case the error of hazard would be 25 per cent.—or 33·33 per cent. if the answer "confused" be regarded as now eliminated from the possibilities. And yet the wrong answer spot "2" is given on 66·67 per cent. of occasions. There is, therefore, here a very definite "positive error" which cannot be explained by the mere taking away of a cortical function, but is rather to be looked upon as conditioned by a distortion of a cortical function. Into this question of "positive error" we shall inquire later.

In the records taken on the five days after the training of the right index finger, the state of "confusion" in answer to tactile stimuli practically disappeared. That is to say, that the subject scarcely ever indicated that he was unable to localize a stimulus.

In the following table (Table XVI) the figures for the localization by the subject of two consecutive similarly located stimuli upon two different spots are given as percentages of the number of times two such similar consecutive stimuli were applied. On comparison with the corresponding Table VI (for the figures before the training of the palmar spots on the right index finger) it will be seen that there is a considerable fall in the average error for spots on the palmar aspect of the right index finger; a considerably smaller fall in the case of these spots on the fourth right digit; little change in the case of the third right digit; and a considerable rise in that of the fifth. There is an even greater fall in this error in the case of the dorsal set of spots on the right index finger.

TABLE XVI.—THE PERCENTAGE NUMBER OF TIMES PAIRS OF TWO CONSECUTIVE SIMILARLY LOCATED STIMULI WERE LOCALIZED ON TWO DIFFERENT SPOTS; GIVEN FOR EACH ASPECT OF EACH FINGER ON THE FIVE DAYS WHICH IMMEDIATELY SUCCEEDED THE TRAINING OF THE PALMAR SET OF SPOTS ON THE RIGHT INDEX FINGER, AND EXPRESSED AS PERCENTAGES OF THE NUMBER OF TIMES TWO SIMILARLY LOCATED STIMULI WERE GIVEN CONSECUTIVELY.

	Finger	Day of Experiment 9	10	11	12	13	Average	Mean variation
Palmar	L 3	0·0	0·0	16·7	0·0	0·0	= 3·3	5·3
	L 4	0·0	0·0	14·3	0·0	11·1	= 5·1	6·1
	R 2	**7·7**	**15·4**	**25·0**	**16·7**	**25·0**	**= 18·0**	**5·6**
	R 3	66·7	0·0	50·0	0·0	50·0	= 33·3	26·7
	R 4	20·0	0·0	50·0	0·0	50·0	= 24·0	20·8
	R 5	50·0	25·0	60·0	100·0	55·6	= 58·1	17·5
Dorsal	L 3	0·0	12·5	33·3	0·0	12·5	= 11·7	9·3
	L 4	0·0	0·0	0·0	0·0	0·0	= 0·0	0·0
	R 2	0·0	0·0	25·0	16·7	12·5	= 10·8	8·7
	R 3	0·0	0·0	66·7	16·7	75·0	= 31·7	31·3
	R 4	0·0	0·0	33·3	12·5	40·0	= 17·2	15·6
	R 5	14·3	12·5	20·0	16·7	66·7	= 26·0	16·2

In Table XVII the number of times two consecutive differently located spots were localized by the subject upon the same spot are given. A comparison with Table VII shows little change in the figures. Table XVIII gives the corresponding figures for cases in which the first of a pair of consecutive dissimilarly located tactile stimuli was rightly localized by the subject, but the second stimulus wrongly localized by him upon the same spot as the first. A comparison with the corresponding Table VIII (for the records before the training of the palmar spots on the right index finger) again shows little change after the training.

TABLE XVII.—THE NUMBER OF TIMES TWO DIFFERENT CONSECUTIVE STIMULI WERE LOCALIZED UPON THE SAME SPOT—GIVEN FOR THE PALMAR AND DORSAL SETS OF SPOTS ON EACH FINGER ON EACH OF THE FIVE DAYS WHICH IMMEDIATELY SUCCEEDED THE TRAINING OF THE PALMAR SET OF SPOTS ON THE RIGHT INDEX FINGER.

	Finger	Day of Experiment 9	10	11	12	13	Average	Mean variation
Palmar	L 3	0	0	0	4	0	= 0·8	1·28
	L 4	0	0	1	0	0	= 0·2	0·32
	R 2	**5**	**5**	**3**	**1**	**6**	**= 4·0**	**1·60**
	R 3	7	2	7	1	10	= 5·4	3·12
	R 4	9	7	2	4	6	= 5·6	2·08
	R 5	5	4	2	7	6	= 4·8	1·44
Dorsal	L 3	0	1	0	2	1	= 0·8	0·64
	L 4	0	0	3	3	0	= 1·2	1·44
	R 2	4	7	2	2	3	= 3·6	1·52
	R 3	1	0	3	4	7	= 3·0	2·00
	R 4	5	5	2	2	8	= 4·4	1·92
	R 5	2	4	3	3	4	= 3·2	0·64

TABLE XVIII.—The number of times the Second of a Pair of Dissimilar consecutive Stimuli was Wrongly Localized on the same Spot as that on which the First of the Pair had been Correctly Localized—given for the Palmar and Dorsal Sets of Spots on each Finger on each of the Five Days which immediately succeeded the Training of the Palmar Set of Spots on the Right Index Finger. (In the case of each Record for each Finger, save that for the Palmar Aspect of the Right Index Finger—"R_2"—there were about Twenty Pairs of Dissimilar Stimuli given; in the case of "R_2" about Forty Pairs were given, and the number of Errors for that Finger has here been Divided by Two.)

		Day of Experiment.													Mean variation
	Finger	9		10		11		12		13		Average			
Palmar	L 3	0	..	0	..	0	..	2	..	0	=	0·4	..		0·64
	L 4	0	..	0	..	1	..	0	..	0	=	0·2	..		0·32
	R 2	**2·5**	..	**2·5**	..	**1·0**	..	**0·5**	..	**4·5**	=	**2·2**	..		**1·16**
	R 3	3	..	1	..	1	..	0	..	6	=	2·2	..		1·84
	R 4	5	..	4	..	1	..	2	..	3	=	3·0	..		1·20
	R 5	3	..	2	..	0	..	5	..	4	=	2·8	..		1·44
Dorsal	L 3	0	..	1	..	0	..	1	..	0	=	0·4	..		0·48
	L 4	0	..	0	..	2	..	2	..	0	=	0·8	..		0·96
	R 2	3	..	4	..	1	..	2	..	1	=	2·2	..		1·04
	R 3	1	..	0	..	2	..	2	..	5	=	2·0	..		1·20
	R 4	4	..	3	..	0	..	2	..	5	=	2·8	..		1·44
	R 5	2	..	3	..	2	..	2	..	3	=	2·4	..		0·48

A comparison of Tables XVI and XVIII seems to show that there is little or no regular relationship between the rates of incidence of these two types of error (one associated with defect of "individuality," the other with defect of "character") in the different fingers on the different days. Both errors may be relatively high in a certain finger, and relatively low in another; while, in yet another finger—or on another occasion—one error may be relatively high, and the other relatively low. But a comparison of the corresponding figures for these errors before the training of the palmar set of spots on the right index finger seems to hint that then there was an indication of a relationship between the two types of error. For when the incidence of one of the types of error is relatively high in a certain finger on a certain day, often the incidence of the other of the types of error in that finger on that day is relatively low (Tables VI, VIII).

(5) *On the Effect of the "training" of the Palmar Set of Spots on the right Index Finger; comparison of the Records before and after it.*

With regard to the effect of the training of the palmar sets of spots on the right index finger, three questions arise. In the first place, did an improvement in the accuracy of the localization of tactile stimuli upon these spots occur after the training, and was this improvement

markedly greater than any which may have occurred in the case of any of the other sets of spots examined in these experiments?

In the second place, provided such an improvement occurred, is it possible to refer it to any definite factors (such as, improvement in the "character" of the spots, improvement in their "individualities," "improvement in their positions"), and does this give us any information with regard to the initial state of badness of localization of tactile stimuli?

And, thirdly, what are the restrictions of the improvement, that is, can it be shown to occur in the case of sets of spots other than the trained ones, or is it confined to these?

Now, there is no doubt that a very definite and striking improvement in the accuracy of localization of tactile stimuli occurred in the case of the "trained" spots on the palmar aspect of the right index finger; and that no such great improvement occurred in the case of any other set of spots.

Table XIX sufficiently demonstrates this. In that table there is given side by side the average per record of the "average error per cent" of localization of tactile stimuli on the palmar and dorsal aspects of each of the fingers, in the first place before the training and in the second place after it.

TABLE XIX.—Comparison of the Errors of Localization on the different Fingers for: A, the Five Days immediately preceding; and B, the Five Days immediately succeeding the Training of the Spots on the Palmar Aspect of the Right Index Finger—expressed as the Average per Record of the "Average Errors per cent."; in Column C the difference between the two Averages is expressed as a Percentage of the First.

		A.		B.		C.
Finger		Average	m.v.	Average	m.v.	Difference of averages
Palmar	L. 3	1·48	2·37	3·44	4·18	+ 1·96
	L. 4	4·52	5·42	1·40	1·68	− 3·12
	R. 2	42·70	3·80	**15·72**	**3·50**	− **26·98**
	R. 3	31·98	8·30	29·68	13·78	− 2·30
	R. 4	46·72	5·96	43·06	2·23	− 3·66
	R. 5	43·06	6·37	40·68	11·30	− 2·38
Dorsal	L. 3	0·66	1·06	6·84	3·59	+ 6·34
	L. 4	2·04	1·63	5·60	6·72	+ 3·56
	R. 2	28·56	7·19	21·62	7·74	− 6·94
	R. 3	18·76	2·94	15·72	9·98	− 2·04
	R. 4	26·80	8·40	20·64	10·21	− 6·16
	R. 5	32·62	9·22	22·16	7·53	− 10·46

It will be seen that there is a very marked fall (from 42·70 per cent. to 15·72 per cent.) in the error for the palmar spots of the right index

finger ("R 2") after the training of them. The difference of these two percentages is about 27 ; and, although there is a slight improvement in the case of the spots on the palmar aspects of the other fingers of the right hand, the difference of the percentages of the finger which shows the greatest improvement after the index finger (the fourth digit) is less than 4. Reckoned as percentages of the larger percentage (that before the training) these differences would be about 63·2 per cent. and 7·8 per cent. respectively. This therefore demonstrates a very great improvement of localization of tactile stimuli on the palmar set of spots of the right index finger, and a slight improvement on these spots of the other fingers of the right hand.

When the figures for the sets of spots on the dorsal aspects of the right fingers are examined, it is seen that in every case an improvement of localization of tactile stimuli has occurred. The greatest improvement occurs in the case of the little finger, but the difference between the two percentages there is 10—about 32 per cent. of the figure before the training of the palmar spots on the index finger.

A great improvement of the localization of tactile stimuli on the three palmar spots of the right index finger therefore occurred—in what did it consist? It is possible to examine here the error for each of the three spots separately, and to examine the kinds of error which were made before and after the training.

Now with regard to the error for each of the three spots—in the following table (Table XX) the total number of times the four possible answers were given in reply to tactile stimuli, applied to each spot of each aspect of the fingers of the right hand, is expressed as a percentage of the total number of times each spot was touched in the tests before and after the training of the palmar set of spots on the right index finger.

Obviously, if the subject knows that the spot touched is one of three possible ones there are four possible answers to each tactile stimulus—that is, "It is on spot 1," spot "2," or spot "3," while the fourth answer is "I cannot decide"—which we may call "confusion." Of the answers spot "1," spot "2," and spot "3" one is right for each spot the tactile stimulus is located upon; in the table the figures for the right answer to each spot are emphasized.

We notice at once that in the case of the right index finger (palmar aspect), whereas the localization of spot "1" was right on 66·67 per cent. of occasions before the training, after the training the percentage rises to 100—no mistakes were made. The difference between these

percentages is about 33. When we examine the figures for the corresponding spot ("1"—the spot on the terminal phalanx) on the palmar aspects of the other fingers of the right hand, and on the dorsal aspects of all the right fingers, we find that in the case of this spot on the palmar aspect of the fourth digit and on the dorsal aspects of the second and fourth digits there is also an improvement. But it is comparatively slight—the difference of the percentages in the case of the greatest of these improvements being about 15. In all the other cases the localization of tactile stimuli upon spot "1" is worse after the training of the right index finger.

TABLE XX.—THE AVERAGE PERCENTAGE PER RECORD OF THE DIFFERENT ANSWERS ("SPOT 1," "SPOT 2," "SPOT 3," AND "CONFUSED") GIVEN TO THE TACTILE STIMULI APPLIED TO EACH OF THE THREE SPOTS ON EACH ASPECT OF EACH FINGER: A, IN THE FIVE RECORDS BEFORE THE TRAINING OF THE PALMAR SET OF SPOTS ON THE RIGHT INDEX-FINGER; AND B, IN THE FIVE RECORDS AFTER THAT TRAINING.

			A. Before. Answers				B. After. Answers			
Finger		Spot	"1"	"2"	"3"	"Con."	"1"	"2"	"3"	"Con."
Palmar	R. 2	*1*	**67·57**	*18·92*	*5·41*	*8·11*	**100·00**	*0·00*	*0·00*	*0·00*
		2	*10·42*	**37·50**	*27·08*	*25·00*	*2·47*	**79·01**	*18·51*	*0·00*
		3	*5·00*	*20·00*	**65·00**	*10·00*	*2·04*	*24·49*	**73·47**	*0·00*
	R. 3	1	**86·67**	8·89	0·00	4·44	**85·71**	11·43	2·86	0·00
		2	7·89	**73·68**	7·89	10·53	14·58	**64·58**	20·83	0·00
		3	4·76	47·62	**40·47**	7·14	4·76	35·71	**59·52**	0·00
	R. 4	1	**74·29**	14·29	2·86	8·57	**84·62**	7·69	7·69	0·00
		2	7·84	**68·63**	11·76	11·76	10·00	**57·50**	30·00	2·50
		3	2·56	66·67	**20·51**	10·26	4·35	65·22	**30·43**	0·00
	R. 5	1	**62·22**	17·78	15·56	4·44	**60·46**	34·88	4·65	0·00
		2	2·22	**53·33**	28·89	15·56	21·95	**58·54**	19·51	0·00
		3	5·71	31·43	**60·00**	2·86	0·00	34·15	**63·41**	2·44
Dorsal	R. 2	1	**54·05**	18·92	5·41	21·62	**68·97**	27·59	3·45	0·00
		2	0·00	**75·00**	18·75	6·25	6·12	**89·80**	4·08	0·00
		3	0·00	7·50	**85·00**	7·50	2·13	21·28	**76·60**	0·00
	R. 3	1	**84·44**	2·22	0·00	3·33	**74·29**	20·00	5·71	0·00
		2	5·26	**65·79**	15·79	13·16	4·17	**91·67**	4·17	0·00
		3	2·38	4·76	**92·86**	0·00	0·00	14·29	**85·71**	0·00
	R. 4	1	**68·57**	8·57	5·71	17·14	**69·23**	28·21	2·56	0·00
		2	9·80	**68·63**	13·73	7·84	7·69	**79·49**	12·82	0·00
		3	7·69	10·26	**79·49**	2·56	4·26	6·38	**89·36**	0·00
	R. 5	1	**62·22**	17·78	6·67	13·33	**58·14**	30·23	11·63	0·00
		2	20·00	**60·00**	4·44	15·56	**4·76**	**88·10**	7·14	0·00
		3	2·86	5·71	**82·86**	8·57	5·00	2·50	**92·50**	0·00

In the case of spot "2" (that on the middle phalanx) a yet greater relative improvement occurs on the right index finger—but error here does not disappear after the training. In the case of no other finger does improvement of localization of the corresponding spot proceed to

such a great extent; and in the case of the palmar aspects of the fingers other than the index finger improvement occurs only in the case of spot "2" on the fifth digit—and there the difference in the percentages is only about 5, whereas in the case of the index finger it is about 42.

In the case of the localization on spot "3" of the palmar aspect of the right index finger (the spot on the basal phalanx) a slight improvement occurs. A similar improvement also takes place in the case of the corresponding spot on the palmar aspects of the third, fourth, and fifth digits (in the case of the third and fourth digits being much greater than the improvement in the case of the trained index finger) and on the dorsal aspects of the fourth and fifth digits (the improvement there being also slightly greater than that in the case of the palmar aspect of the right index finger); the localization of spot "3" on the dorsal aspects of the right second and third digits is worse after the training of the palmar set of spots on the index finger.

It may perhaps be inferred that the improvement of the accuracy of localization of tactile stimuli upon spot "3" on the palmar and dorsal aspects of all the fingers is a more or less general one; but that the great improvement of localization on spots "1" and "2" on the palmar aspect of the right index finger is a special one conditioned by the training given to that set of spots on this finger.

When the answers for the palmar aspects of the right index finger are examined, it is seen at once that "confusion" disappears after the training. In the case of tactile stimuli applied to spot "1" the wrong answers spot "2" and spot "3" also disappear; but in the case of spot "2"—while "confusion" does not occur after the training—the wrong answers spot "1" and spot "3" are only reduced. The reduction is, however, large and the increase in the accuracy of the localization of stimuli applied to this spot may perhaps be looked upon as conditioned by the absence of confusion—the decision now being made in the right direction, and by the reduction of the wrong replies. When the answers to spot "3" are examined it is seen that the wrong reply spot "1" is given slightly less often after the training, and the wrong reply spot "2" slightly more often. These differences are small, and the increase in the proportion of right answers may perhaps be looked upon as conditioned by the absence of confusion—as it were the decision being now made, and in the right direction. It will be seen that "confusion" practically disappears for all the fingers after the training of the right index finger; but it is by no means the case that the

improvement of the accuracy of localization of a spot is greatest where the proportion of "confusion" answers was greatest before the training of the right index finger.

An interesting point is exhibited by this table. Where, before the training of the right index finger, the proportion of confusion answers is great for all the fingers the proportion of each answer to each spot should have been about 25 per cent. had the answers been selected by hazard. After the training of the index finger it is perhaps fairer to assume that, as "confusion" practically disappears for all the fingers, the hazard proportion should have been about 33·3 per cent. for each answer. Now, when the table is examined, it is seen that in the case of several answers the proportion is greater than that of hazard. Except in the case of the right answer to spot "3" on the palmar aspect of the fourth right digit both before and after training of the index finger, this is uniformly so both before and after the training for the correct answers to each spot on each aspect of each finger. In other words, there is almost uniformly a positive bias in the direction of the correct answer. But when the incorrect answers are examined it is seen that in certain cases there is an error greater than the error of hazard. (Finger R 2—answer spot "3" to stimuli on spot "2"; R 3—spot "2" to spot "3"; R 4—spot "2" to spot "3"; R 5—spot "3" to spot "2," and spot "2" to spot "3"—all on the palmar aspects of the fingers, no instance on the dorsal, before training; and R 3—answer spot "2" to stimuli on spot "3"; R 4—spot "3" to spot "2," and spot "2" to spot "3"; R 5 spot "1," spot "2" to spot "3"—all on the palmar aspects of the fingers after training, and, perhaps, R 2—answer spot "2" to stimuli on spot "1"; R 4—spot "2" to spot "1"; R 5—spot "2" to spot "1"—all on the dorsal aspects of the fingers after training of the spots on the palmar aspect of the index-finger). In the case of stimuli applied to spots "2" and "3" on the palmar aspects of the fingers there seems to be a fairly definite incorrect identification of "2" with "3" and "3" with "2." In the case of the dorsal sets of spots there is, after the training of the palmar set of spots on the right index finger, a most curious increase of the mistake of localizing stimuli which were applied to spot "1" upon spot "2"—and this is the case for all the fingers. After the training of the palmar spots of the index finger this mistake becomes positive—greater than the error of hazard.

Before we leave this table it may be noticed that in the case of the answer spot "1" this error diminishes for spots "2" and "3" on the

palmar aspect of the right index finger (trained) along with the increase of accuracy of localizing stimuli applied to spot "1" itself; but there is no corresponding decrease in this error for spots "2" and "3" in the case of the other fingers (except perhaps in the case of spot "3" on the little finger) and no corresponding increase of accuracy of the localization of spot "1" on these fingers. From this it would appear that the effect of the training is not spread over the other fingers—but we shall return to this question later.

In Table XXI the average number of times two consecutive similarly situated stimuli were localized upon different spots is given for the records before and after the training of the palmar spots on the right index finger. It will be seen that a considerable decrease in this form of error took place in the case of the palmar and dorsal sets of spots on the right index finger; that a considerable decrease took place for the dorsal set of spots on the little finger; and that a great increase occurred in the case of the palmar spots of the little finger. In the other instances the variation is probably negligible.

TABLE XXI.—Comparison of the Average number of times per. cent. per Record that Pairs of Two consecutive similarly situated Stimuli were Localized upon two different Spots: A, Before the Training of the Palmar Set of Spots on the Right Index Finger; and B, After that Training.

		A		B		
Finger		Average	m.v.	Average	m.v.	Difference of averages
Palmar	L. 3	8·0	12·8	3·3	5·3	− 4·7
	L. 4	5·0	8·0	5·1	6·1	+ 0·1
	R. 2	40·0	16·0	**18·0**	**5·6**	− **22·0**
	R. 3	34·5	19·6	33·3	26·7	− 1·2
	R. 4	32·3	7·9	24·0	20·8	− 8·0
	R. 5	28·3	12·8	58·1	17·5	+ 29.8
Dorsal	L. 3	2·9	4·6	11·7	9·3	+ 8·8
	L. 4	7·5	9·0	0·0	0·0	− 7·5
	R. 2	38·0	17·6	10·8	8·7	− 27·2
	R. 3	23·8	12·4	31·7	31·3	+ 7·9
	R. 4	25·5	1·37	17·2	15·6	− 8·3
	R. 5	48·3	24·2	26·0	16·2	− 22·3

The chief point of interest is that here the improvement of this error in the case of the right index finger applies not only to the trained spots on the palmar aspect but also to the untrained ones on the dorsal aspect.

In Tables XXII and XXIII the errors in which the same answer was given to two consecutive stimuli which were situated on different spots are compared for the records before and after the training of the palmar spots on the right index finger—in the second table the figures apply

only to those errors in which the first spot was correctly localized and the second incorrectly, on the same spot as the first. It is seen that, although this error decreases for the palmar spots of the right index finger, the decrease is not so great as that in the case of some of the other fingers.

TABLE XXII.—Comparison of the Average number of times per Record two different consecutive Stimuli were Localized upon the same Spot: A, Before the Training of the Palmar Set of Spots on the Right Index Finger; and B, After that Training.

		A		B		
	Finger	Average number	m.v.	Average number	m.v.	Difference of averages
Palmar	L. 3	0·0	0·0	0·8	1·28	+ 0·8
	L. 4	0·8	0·96	0·2	0·32	− 0·6
	R. 2	5·4	2·5	**4·0**	**1·60**	− **1·4**
	R. 3	4·8	1·4	5·4	3·12	+ 0·6
	R. 4	5·6	2·1	5·6	2·08	0·0
	R. 5	6·8	1·8	4·8	1·44	− 2·0
Dorsal	L. 3	0·0	0·0	0·8	0·64	+ 0·8
	L. 4	0·8	0·6	1·2	1·44	+ 0·4
	R. 2	3·8	0·6	3·6	1·52	− 0·2
	R. 3	3·4	1·9	3·0	2·00	− 0·4
	R. 4	4·2	1·5	4·4	1·92	+ 0·2
	R. 5	4·4	1·1	3·2	0·64	− 1·2

TABLE XXIII.—Comparison of the Average number of times per Record the Second of a Pair of consecutive dissimilar Stimuli was Wrongly Localized upon the same Spot as that on which the First Stimulus had been Correctly Localized: A, Before the Training of the Palmar Set of Spots on the Right Index Finger; and B, After that Training.

		A		B		
	Finger	Average number	m.v.	Average number	m.v.	Difference of averages
	L. 3	0·4	0·64	0·4	0·64	0·0
	L. 4	0·2	0·32	0·2	0·32	0·0
	R. 2	2·4	0·96	**2·2**	**1·16**	− **0·2**
	R. 3	2·8	0·64	2·2	1·84	− 0·6
	R. 4	2·6	1·52	3·0	1·20	+ 0·4
	R. 5	3·6	1·12	2·8	1·44	− 0·8
Dorsal	L. 3	0·0	0·00	0·4	0·48	+ 0·4
	L. 4	0·6	0·48	0·8	0·96	+ 0·2
	R. 2	2·0	0·80	2·2	1·04	+ 0·2
	R. 3	1·8	1·04	2·0	1·20	+ 0·2
	R. 4	2·0	0·80	2·8	1·44	+ 0·8
	R. 5	2·6	0·88	2·4	0·48	− 0·2

It is interesting to compare Table XXIII with Table XXI. It is then seen that there is little correspondence between the two kinds of error. For a set of spots on one finger both errors may fall after the training; or both may rise; or one may rise and the other may fall.

Before we pass to the consideration of these results one more analysis may be given—that of the occurrence of "dilemma" before and after the training of the index finger. The observation of this phenomena depends very largely upon the experimenter, and the figures here are given with this reservation—for it is extremely difficult to determine in what the dilemma consists. In our experiments the subject pointed with a pencil to the spot on the hand of the model which he supposed to correspond with the spot on his own hand which had just been touched. In doing this he usually placed the point of the pencil directly upon the spot which he wished to indicate. Occasionally the latency of this act was obviously much greater than usual; and then we sometimes counted the answer as one which exhibited "dilemma." But more usually there was a very distinct indication of the presence of dilemma. The pointer would hover over the spots on the hand of the model—now over one, now over another—and finally the subject would either place the pointer upon one of the spots (in which case we called the answer one characterized by dilemma), or would touch the table in indication that he was unable to locate the tactile stimulus (in which case we called the answer "confusion"). In all these records no word was spoken from beginning to end, and our difficulty was to distinguish "dilemma" from mere delay of response where the pointer did not hover between different spots, and to notice the small indications of this hovering which sometimes occurred. One very marked change occurred after the training of the palmar set of spots on the right index finger, but we had no instruments to record it. The latency of the localizing act of the subject was always very much greater for stimuli applied to the right hand than for those applied to the normal left hand. After the training of the palmar set of spots on the right index finger the latency of their localization was markedly less than that of the localization of tactile stimuli upon the palmar spots of the other fingers; but it never became as small as that of the localization of spots on the left hand.

In the following table (Table XXIV) the number of times dilemma occurred in the five records before the training of the right index finger and in the five records after that training is given. A distinction is drawn between cases of dilemma in which the final answer was wrong and cases in which it was right.

The decrease of this phenomenon after the training of the palmar spots on the right index finger is seen to occur generally for all the sets of spots examined, and not to be greater in the case of the index finger than in the cases of the other fingers. We do not give a more minute

analysis, for our figures give no indication of a relation between the number of times dilemma occurred and the relative accuracy of localization either for the set of spots on a finger or for any one of these spots.

TABLE XXIV.—A COMPARISON OF THE NUMBER OF TIMES "DILEMMA" OCCURRED: A, IN THE RECORDS BEFORE THE TRAINING OF THE PALMAR SET OF SPOTS ON THE RIGHT INDEX FINGER; AND B, IN THE RECORDS, AFTER THAT TRAINING. IN THE COLUMNS THE FIRST NUMBER DENOTES THE TIMES THE FINAL RESULT OF THE DILEMMA WAS WRONG, THE SECOND NUMBER THE TIMES THE FINAL RESULT WAS RIGHT, AND THE THIRD GIVES THE TOTAL OF THE TWO.

		A BEFORE			B AFTER		
	Finger	Wrong	Right	Total	Wrong	Right	Total
Palmar	L 3	0	0	0	0	0	0
	L 4	0	1	1	0	0	0
	R 2	3	11	14	**3**	**5·5**	**8·5**
	R 3	3	16	19	0	7	7
	R 4	4	12	16	4	5	9
	R 5	6	9	15	3	2	5
Dorsal	L 3	0	0	0	0	0	0
	L 4	1	1	2	0	4	4
	R 2	5	15	20	2	6	8
	R 3	3	14	17	0	5	5
	R 4	3	22	25	0	6	6
	R 5	1	17	18	0	7	7

We may now summarize the results which were obtained after the training of the palmar set of spots on the right index finger.

In the first place a general improvement of the localization of tactile stimuli occurred for all the sets of spots examined in this experiment. But a much greater improvement occurred in the case of the trained set of spots than in the case of any other set, and we are probably justified in attributing the improvement to the training.

This improvement in the case of the trained palmar set of spots was most marked in the case of spot "1" (on the terminal phalanx) and spot "2" (on the middle phalanx). In the localization of the first of these all error disappeared after the training; in the localization of the second each type of error markedly decreased. In the localization of spot "3" (basal phalanx) little change occurred in the different types of error, save that "confusion" disappeared.

Now this improvement might (on our hypothesis) be due (1) to an improvement in the attribute of character of the trained spots (whereby they are recognized as different amongst themselves); or (2) to an improvement of the attribute of individuality (whereby stimuli applied to a specific spot are recognized as similarly located); or (3) to an

improvement of the attribute of position (whereby the tactile stimulus is referred to a special spot on the surface of the body).

In the early records of the experiment—those taken before the training of the right index finger—there was a great tendency for the answers to run in consecutive series, although the stimuli were applied indifferently to the different spots. This is what would be expected to occur if the attribute of character of the tactile stimuli was lost, or at any rate impaired.

In the training which we gave to the palmar spots on the right index finger, the subject in one part of it especially concentrated his attention on the difference between the tactile stimuli which he could then see being applied to the different spots in an indifferent order.

TABLE XXV.—A comparison of the total number of times Series of consecutive similar Answers of different lengths were given: A, in the Records Before the Training of the Right Index Finger; and B, After that Training; the Second columns give Arbitrary Figures obtained by Multiplying the Number of Series in the First columns by the Number of Answers in the Series (2, 3, 4, &c.). The Figures for the Dorsal Sets of Spots are not given.

	A. Before			B. After		
Finger	No. *in* series	No. *of* series		No. *of* series		
R 2	2	7	14	7	14	
	3	7	21	3	9	
	4			1	4	
	5	1	5	1	5	
	6					
	7					
	8			0·5	4	
	9	1 = 16	9 = **49**	= 12·5		= **36**
R 3	2	7	14	11	22	
	3	5	15	1	3	
	4	1	4	3	12	
	5	1	5	2	10	
	6	1 = 15	6 = **44**	1 = 18	6 = **53**	
R 4	2	3	6	11	22	
	3	3	9	5	15	
	4	3	12	5	20	
	5	4	20	1	5	
	6			1	6	
	7	1 = 14	7 = **54**	= 23		= **68**
R 5	2	14	28	13	26	
	3	3	9	6	18	
	4	1	4	2	8	
	5	3	15			
	6	2 = 23	12 = **68**	1 = 22	6 = **58**	

After the training the records show a reduction in the number of such consecutive series of similar answers for the spots on the palmar aspectof the right index finger. In the cases of the third and

fourth right digits an increase in this number occurred—that increase being a considerable one in the case of the fourth. While the number in the case of the fifth digit was practically stationary. The figures are given in Table XXV.

This would seem to demonstrate that one of the initial factors in the subject's badness of localization of tactile stimuli consisted in the impairment of the attribute of " character " of the tactile stimuli —the attribute whereby the subject is conscious that tactile stimuli located upon different spots are, in some manner, dissimilar—and that the effect of the training of the spots on the right index finger was to reduce this error for them, but not (at any rate to the same extent) to reduce this error for the spots on the other fingers. It must, however, be noticed that when these figures are analysed in terms of pairs of dissimilarly located stimuli, the first of which is correctly localized by the subject and the second wrongly upon the same spot as the first, the error is not more greatly diminished for the index fingers than for the others (Table XXIII)—but this is perhaps only a part of the special type of error which we are examining.

It would, therefore, seem that impairment of the attribute of character was one of the factors in the initial condition of the subject's inaccuracy of localization of tactile stimuli, and that this impairment was reduced by training a specific set of spots. But it must be noted that the hypothetical attribute of character may not be eliminated—only impaired; for even in the earliest records there were portions where the answers did not run in series, and where at times the localization of tactile stimuli was accurate.

When the early records are examined it is found that at times series of consecutive similarly located stimuli were localized by the subject upon different spots. At these times the answers, of course, did not run in similar series; and the inference (on our hypothesis) is that this error was conditioned by impairment of the attribute of " individuality " in the localization of tactile stimuli—the attribute whereby the subject knows that tactile stimuli applied to the same spot are in some manner similar to each other.

In a part of our training the subject paid special attention to the similarity between tactile stimuli which he saw being applied in consecutive series to a single spot.

After that training the records show a decrease in this type of error—the localizing of consecutive similarly located stimuli upon dissimilar spots—in the case of the trained spots. But there is also a

decrease in the case of the untrained spots on the back of the trained finger. From this it might be inferred that this attitude is, as it were, common to various sets of spots on a finger; but in the case of the little finger a marked increase of error took place for the palmar set of spots, and a marked decrease for the dorsal, after the training of the index finger. When the palmar sets of spots on the fingers are alone considered, the decrease in this type of error is seen to be much less in the cases of the third and fourth digits than in the case of the trained index finger; while an increase of error occurs in the case of the fifth digit (Table XXI).

It may, perhaps, be inferred that this error decreased after the training of the palmar set of spots on the right index finger for that finger, and not to so great an extent for the palmar sets of spots of the other fingers of the right hand; that this error is conditioned by impairment of the attribute of individuality in the localization of tactile stimuli; and that the training reduced this impairment.

If so, we may regard the original condition of the subject as conditioned in part by impairment of the attribute of character, and in part by impairment of the attribute of individuality.

But for the complete and accurate localization of tactile stimuli there is necessary (on our hypothesis) the attribute of "position." In the subject whose state we examined this attribute can hardly have been lost; for then it would be expected that he would have been unable to localize the tactile stimuli; whereas one of the features of this case was the comparatively small proportion of instances in which he could not locate a stimulus. But there seems to be evidence for a definite distortion of this attribute.

That this is so is shown by the occurrence of "positive error" in the localization of certain spots. The error which he made in the localization of certain spots was greater than the error of hazard. In such a case the subject had three choices (excluding the possible "confusion" answer). One of these was the correct answer, and the other two were incorrect. Now, when these errors are analysed (Table XX, see analysis in text), it is seen that in some cases a certain wrong answer would be given more often than the error of hazard. In such cases a distortion, probably of the attribute of position, must be assumed. That is to say, that in certain instances the subject showed a definite tendency to place a certain specific tactile stimulus upon a certain wrong spot rather than upon a certain other wrong spot. The "position" of the tactile stimulus had in some manner been distorted.

This occurred in the case of one of the wrong answers given to spot "2" on the palmar aspect of the right index finger. That was one of the two trained spots which most definitely showed improvement of localization after the training. In the records taken after the training, this positive error was reduced considerably below the error of hazard, but this reduction was not accompanied by an increase on the other possible wrong localization of this spot. In one of the other cases of positive error which occurred in the other fingers before the training of the right index finger, a reduction below the error of hazard also occurred; but in this case that reduction was accompanied by a marked increase in the other possible error in the localization of that spot.

It may, perhaps, be assumed that part of the initial condition of this subject's inaccuracy of localization of tactile stimuli was due to a distortion of the attribute of position; and that after the training this distortion was reduced for the spots which were trained.

One further point with regard to the analysis of the effects of the training—the question whether it was confined to the trained spots or was seen also in others—may be left over to the following subsection of this paper.

(6) *On the Question whether the Improvement in Accuracy of Localization after Training was confined to the Spots which were trained.*

To a certain extent this question may at once be answered. An apparent general improvement of all the spots on the back and front of the fingers occurred after the training of the palmar set of spots on the right index finger. This apparent general improvement was, however, much less than the special improvement of the trained set of spots.

Now, although such an apparent general improvement took place, it cannot definitely be ascribed to the training of a special set of spots. Thus it is, perhaps, possible that the mere repetition of the test might be accompanied by a general improvement in the subject's responses—even although he was never allowed to know when his replies were right or when they were wrong.

To test the possible general effect of the training we used the following method: A second set of spots was selected on the palmar aspect of each finger. These spots lay on the folds of skin which are situated near the inter-phalangeal and metacarpal-phalangeal joints—whereas the spots of the sets which we used in the daily examinations lay over the middle of the phalanges. The set of spots which were

examined from day to day (and were trained on the right index finger) we may term the "ordinary spots" or the "trained spots"; while the other set of spots, which was examined, but rarely so that there might be little or no effect of practice, we may term the "untrained spots," because no set of them were trained.

We had not thought of selecting these second sets of spots before the commencement of the training of the spots on the right index finger, and so we are unable to compare the average errors for the two sets of spots on each finger before the records were complicated by the training. It is possible that the errors were not the same (or not very nearly the same) for the two sets of spots. In another case, which was in almost every respect similar to that which we now describe, we found that the error of localization of tactile stimuli was distinctly greater for the sets of spots over the joints than for the sets of spots which were placed over the middle of the phalanges—although in this case the subject thought that he could localize the former spots more accurately than the latter. When the localization is carried out in an exactly similar manner on the ordinary subject there is little or no difference in the accuracy of localization of supra-liminal tactile stimuli on these two sets of spots—at any rate, with the instrument which we used.

After the training of the palmar set of "ordinary spots" on the right index finger we examined on three occasions the accuracy of localization for the "untrained spots" on the fingers. Two of these examinations were done on the twelfth day of the experiment, and the third on the thirteenth. The following table gives the average error per cent. of localization:—

TABLE XXVI.—Average Error per cent. of Localization on the "Untrained" Sets of Spots on the Palmar Aspects of the Fingers after the Training of the "Ordinary" Set of Spots on the Right Index Finger.

	Day of Experiment								
Finger	12		12a		13		Average
Palmar L 3	..	18·0	..	4·8	..	0·0	=	7·6
L 4	..	13.7	..	3·3	..	7·0	=	8·0
R 2	..	**60·0**	..	**65·3**	..	**48·1**	=	**57·8**
R 4	..	37·6	..	35·2	..	47·3	=	40·0
R 3	..	28·7	..	55·6	..	41·2	=	41·8
R 5	..	54·1	..	27·6	..	52·9	=	44·9

A glance at this table shows that the index finger ("R. 2") is actually the worst of the four fingers of the right hand. That is to say that this finger—which at this time, after the training, was the best of the four

as regards the localization of tactile stimuli on the "ordinary" spots—is much the worst for the localization of these stimuli when a strange set of spots is selected for examination. The figures in columns 12 and 13 of this table should be compared with those in the corresponding columns (12 and 13) of Table XIV. The latter figures are those for the "ordinary" spots on the same day. Especially when the figures in the column 13 are examined, it will be seen that there is considerable similarity between them as regards the third, fourth, and fifth digits—but that there is a considerable difference when the figures for the second digit (index finger) are examined. The percentage of error is 23·5 for the "ordinary" spots on that finger, and 48·1 for the "untrained" spots; a still greater difference (7·6 per cent. as against 60 per cent.) occurs in column 12. The column of averages may be compared with those in Table XIX ("ordinary" spots, before and after training of right index finger).

TABLE XXVII.—The Total Percentage Error of Localization for each of Spots 1, 2, and 3 of the "Untrained" Sets on the Palmar Aspects of the Fingers in the Three Records given in Table XXVI.

	Spot		
Finger	1	2	3
Palmar L 3	14·9	3·7	0·0
L 4	7·4	16·7	0·0
R 2	**73·3**	**50·0**	**50·0**
R 3	66·7	42·4	11·1
R 4	45·8	29·6	50·0
R 5	13·9	66·1	51·2

The next table (Table XXVII) gives the average error of localization for each of the three "untrained" spots on each finger in these three records. The corresponding figures for the "ordinary" spots before training the right index finger are given in Table II, and those after the training in Table XV. A comparison of these two tables with the present one demonstrates scarce a point of resemblance. The incidence of error as regards the distal, intermediate, and proximal spots (spots "1," "2," and "3") seems to have no common basis when the figures for the "ordinary" and "untrained" sets of spots are examined. This strongly suggests that the different sets of spots on the same aspect of the same finger have little or nothing in common. On comparison of the figures for spot "1" on the right index finger in this table and in Table XV it will be observed that in the latter case, after training, error has absolutely disappeared; but in the former case (that is, an "untrained" spot which lies in a corresponding position in its set) the

error is as great as 73·3 per cent., and is greater than that of either of the other spots in the set.

The conclusion from these figures would seem to be that the training of a set of spots on a certain finger, although very definitely reducing the error in the localization of tactile stimuli for the trained set of spots, does not reduce the error for other and untrained sets of spots on the same finger. Arguing from this alone, it might be said that the effect of training is confined to the trained spots, and is extended neither to other spots on the trained finger nor to spots on the other fingers. The apparent increase of accuracy in the localization of tactile stimuli on the "ordinary" spots of the other fingers (as shown by our experiments) might then be supposed to be conditioned merely by the effect of practice.

But in this connection it must be noted that the spots which exhibited an increase of accuracy of localization on the other fingers lay in corresponding positions to the trained spots on the right index finger. It might be that the training of the spots on the right index finger was accompanied by a slight increase in accuracy of localization for the corresponding spots on the other fingers—but not by an increase in accuracy for the differently lying spots either on the trained finger or on the other fingers. An examination of the figures in Table XX shows, however, that the increase in the accuracy of localization in the "ordinary" spots of the untrained fingers does not take place to any appreciable extent in the spots ("1" and "2") which correspond to those which exhibit a marked increase of accuracy of localization in the case of the trained finger; but occurs chiefly in a spot ("3") which on the trained finger exhibits comparatively small increase of accuracy. We are, therefore, probably correct in ascribing the general increase in the accuracy of localization on all the fingers to a general process—perhaps to that associated with "practice."

Another point of interest arises in connection with a possible extension of the effect of the training of the spots on a single finger. In each of the records examined so far, the subject was allowed to know which finger was being stimulated at any one time. Now, for accurate localization of a tactile stimulus, the subject must be aware in the first place of the part of the body which is touched, and in the second place of the place of the spot which is touched upon that part. The part of the body is, of course, a relatively ill-defined concept in the case of most subjects; the subject may have difficulty in defining where the wrist ends and the forearm begins. But, for our purposes, it is perhaps

sufficient to suppose that "front of finger" (or merely "finger") and "place on finger," were two elements in the "position" of the spots which we were examining. Now, error in the first of these elements was eliminated for most of our records by allowing the subject to know which finger was being touched.

But as the experiment proceeded there occurred a definite increase in the accuracy of localization of tactile stimuli on the trained spots of the trained finger. The interesting question arose—does the training of a set of spots on a finger under these conditions enable the subject more accurately to locate tactile stimuli upon that finger than upon the others when he is not allowed to know which finger is being touched? In other words, did the increase of accuracy of localization extend to the element "finger" as well as to the element "place on finger" in the "position" of spots on the trained finger, or was it confined to the element "place on finger"?

To examine this point we used a test in which the "ordinary" spots were touched upon the different fingers in an indifferent order—so that no one finger was often touched twice in succession.

The analysis of such a test is one of difficulty. Here we confine ourselves to the examination of the errors in placing the spot touched irrespective of the fingers, and in localizing the fingers touched irrespective of error in the placing of the spot. Obviously, the finger may be right and the spot on it may be wrongly placed; or the spot may be correctly placed, but upon the wrong finger; or both finger and place on finger may be correctly localized, or both may be wrong. We must refer to a point which touches the accuracy of our results. These tests were comparatively short ones. Except in the case of the last in this series, an average of a little more than 6 stimuli were applied to each finger in each test, and of a little more than 8 to each position of the three spots. In the last test about 50 stimuli were given to each finger, and about 67 to each position of the three spots—that is, about 16·7 stimuli to each individual spot.

We began this test—which may be termed the "unknown finger" test—the day before the training of the "ordinary" spots on the palmar aspect of the right index finger; and continued it, with one exception, every day thereafter. In Tables XXVIII and XXIX the figures are given for the record taken before the commencement of the training of the right index finger and for the two records taken immediately after the commencement of it.

In Table XXVIII the percentage error of localization of each indi-

vidual spot is given without reference to the rightness or wrongness of the finger upon which it was localized. The averages for each of these three spots are rather larger than the corresponding ones for the first five records in this experiment (obtained from Table II). Thus: "1" = 20·5 per cent.; "2" = 30·5 per cent.; "3" = 49·4 per cent.; average of the three = 33·5 per cent. Whereas in the first five records, taken before the training of the right index finger was commenced, these averages were: "1" = 27·3 per cent.; "2" = 41·7 per cent.; "3" = 53·5 per cent.; average of the three = 40·8 per. cent.

TABLE XXVIII.—The Percentage Error of Localization of the Individual Spots, "1," "2," and "3," in the "Unknown Finger" Test upon three separate days: the First before Training of the Palmar Set of Spots on the Right Index Finger, the Second on the day after the Commencement of that Training, the Third on the Second Day. Immediately underneath these Percentages is given the Average of the Three Percentage Errors; below that is given the Average Percentage Error of the Best Finger in the Ordinary Test taken immediately before the "Unknown Finger" Test; and below that again is given Average of the "Average Errors per cent." of all Four Right Fingers (Palmar Aspects) in that Ordinary Test.

	Day of Experiment						
	5		6		7		Average
Spot 1	22·2	..	25·0	..	14·3	=	20·5
Spot 2	42·9	..	15·4	..	33·3	=	30·5
Spot 3	56·6	..	25·0	..	66·7	=	49·4
Average of above errors	40·5	..	21·8	..	38·1	=	33·5
Average error per cent. of *best* finger in ordinary test, same day ..	41·4 (R. 2)	..	21·1 (R. 5)	..	37·2 (R. 2)	=	33·2
Average of average errors per cent. of all four fingers in ordinary test	50·9	..	37·3	..	46·8	=	45·0

A most interesting point is revealed when the average error per cent. of the three spots in each of the "unknown finger" tests is compared with the "average error per cent." of the different fingers in the ordinary test on the same day. It might have been thought that as in this test the spots are touched in an indifferent order upon the different fingers, and that as the accuracy of localization of tactile stimuli differs upon the different fingers when these are examined separately, the error in the "unknown finger" test would be of nearly the same value as that of the average of the errors of the separate fingers in the ordinary test. This is not the case. That average is given for each day on the lowest line of Table XXVIII, and it is seen to be considerably greater than the error in the "unknown finger" test. But the average error per cent. of the best finger (that on which the error was lowest) in the ordinary test approximates very closely to the average error in

the "unknown finger" test. The average error of the best finger is given immediately above that for all the fingers in Table XXVIII. Immediately above it again is given the average error in the "unknown finger" test, and the close approximation is evident. It will be observed that, upon the whole, the average error of the best finger in the ordinary test is somewhat less than the average error in the "unknown finger" test.

This result is of course obtained from a relatively small number of observations, and the smallness of these may lead to inaccuracy. But the result is a most curious one. It would seem as if in a manner the "oneness," "twoness," or "threeness" of a spot (that is, its relative position on the finger; the touches, of course, being each single) is a general character common to the spots on the different fingers if no restriction of the touched spots to a single finger is made.

But it must be remembered that in the ordinary test considerable variations occur in the accuracy of the localization of tactile stimuli upon the different fingers. This observation would seem to be antagonistic to that described above. Were the error of localization merely a negative one, and were it due to the elimination of a part of the normal mechanism or to the destruction of a part of the normal process, it would be a matter of difficulty to reconcile the two observations. But perhaps the conception of "positive error" or the distortion of the mechanism (or process) makes such a reconciliation possible.

Thus, if the condition was merely one of negative error the restriction of the test to a single finger would in no manner inconvenience the subject. If he has, as it were, a remnant of the normal process of the cerebrum whereby (on one side) the localization of tactile stimuli is conditioned, the restriction of the investigation to a single finger will in no way impede his correct localizations; while the incorrect ones will be as easily localized upon that finger as upon any other. But if there is "positive error," if the cerebral mechanism is definitely distorted in some manner or other, the subject may feel that a tactile stimulus upon the finger to which the experiment is restricted is really and definitely localized upon another finger—although he knows from the conditions of the experiment that this is not so. Some sort of definite effort is then required on the part of the subject to make the localization on the finger to which the experiment is restricted; and such efforts may well disturb the accuracy of his results. Thus spot "3" on the little finger is touched; the subject may feel that the spot touched is spot "3" on the palmar aspect of the fourth right digit; yet he knows

that it must be located somewhere upon the little finger. He then supposes that the spot is more like spot "2" on the little finger than spot "3" on that finger. The result is that he makes an inaccurate localization—whereas the place of the spot would have been correct if he had made the localization upon the fourth finger—although then the finger element in the localization would have been incorrect.

This supposition is not a fanciful one. The subject of these experiments occasionally told us—in the earlier records—that he felt that the spots which were being touched lay upon another finger than that upon which he knew (from the conditions of the experiment) they must lie. He said, "The other finger seems to draw them away."

The training was not directed to the correction of error as regards the finger upon which the spots lay, but only to the correction of error as regards the place of the spots on the finger. Distortion of the "finger" element in the "positions" of the tactile stimuli may well have been a factor in the error of localization when the test was done on restricted spots on the restricted fingers. When the restriction of the fingers was removed in the "unknown finger" test this distortion may have been removed, and the localization of the place of the spot irrespective of the localization of the finger upon which the spot lay may have been freed.

Another point must, however, be noted in connection with these observations before the training of the ordinary spots on the right index finger. Although the average error of localization of the three spots irrespective of the fingers upon which they lay in the "unknown finger" test was nearly similar to the average error per cent. of the best finger in the ordinary test (in which each finger was examined separately), the incidence of error as between the three individual spots was not similar in the two tests. Thus the localization of spot "1" might be relatively bad in the "unknown finger" test—as compared with that in the ordinary test—and so on, yet the two averages for all three spots might show close agreement.

When the errors of localization of the fingers (irrespective of localization of the spots upon the fingers) are examined it is seen that considerable variation occurs (Table XXIX).

Here the error of hazard should be 75 per cent. The table shows that this is greatly exceeded in the case of the fifth digit—the worst of the four as regards this error; and it is slightly exceeded in the case of the fourth. It was especially in the case of the little finger that the subject in the earlier records felt that the spots touched were on another

finger—usually the fourth. Here is confirmatory evidence of the existence of "positive error" in the localization of tactile stimuli upon a certain finger irrespective of their localization upon that finger itself. As it were, there was a distortion of the element of "finger" in the position of the stimuli applied to a certain set of spots. There was little or no confusion, only a definite reference of the spots to another finger.

TABLE XXIX.—THE PERCENTAGE ERROR OF LOCALIZATION OF THE INDIVIDUAL FINGERS IN THE "UNKNOWN FINGER" TEST ON THE SAME THREE DAYS AS IN TABLE XXVIII.

	Day of Experiment			
Finger	5	6	7	Average
R 2	**16·7**	**83·3**	**57·1**	**= 52·4**
R 3	50·0	28·6	20·0	= 32·9
R 4	66·7	33·3	80·0	= 76·7
R 5	85·7	100·0	62·5	= 82·7

Tables XXX and XXXI compare respectively with Tables XXVIII and XXIX, and they give the corresponding figures for the five days after the training of the palmar set of spots on the right index finger.

TABLE XXX.—THIS TABLE IS SIMILAR TO THAT GIVEN IN XXVIII, BUT THE FIGURES NOW ARE THOSE OBTAINED ON THE FIVE DAYS WHICH IMMEDIATELY FOLLOWED THE TRAINING OF THE RIGHT INDEX FINGER. THE FIGURES IN SQUARE BRACKETS GIVE THE AVERAGES AFTER EXCLUDING RECORD "10."

	Day of Experiment.					
	9	10*	11	12	13	Average
Spot 1	0·0	85·7	0·0	0·0	23·7	= 21·9 [5.9]
Spot 2	20·0	50·0	20·0	20·0	25·7	= 27·1 [21·4]
Spot 3	37·5	75·0	0·0	12·5	50·7	= 35·1 [25·2]
Average of above errors	19·2	70·2	6·7	10·8	33·4	= 28·1 [17·5]
Average error per cent. of *best* finger in ordinary test, same day	16·7 (R. 2)	6·1 (R. 3)	15·7 (R. 2)	7·6 (R. 2)	23·5 (R. 2)	= 13·9 [15·9]
Average of average errors per cent. of all four fingers in ordinary test	37·6	21·3	31·9	28·3	41·9	= 32·2 [34·9]

* On this day the subject had been for too long a walk and had just come in, rather breathless, before the test.

In these tables we are, perhaps, justified in eliminating the record for the tenth day—as on that occasion the subject had just returned from a longer walk than he had yet attempted, and had hurried in the last part of it, as he was late. From Table XXX it will be seen, even including this record, that the error as regards the position of the spots irrespective of the finger upon which they were localized is in every case considerably less than before. As compared with the average of

the percentage errors of localization of each individual spot on all the fingers in the five ordinary tests after the training, the errors for the individual spots in the "unknown finger" test show considerable diminution except in the case of spot "1." Thus: ordinary test (averages obtained from Table XV)—spot "1" = 17·3 per cent.; spot "2" = 35·1 per cent.; spot "3" = 43·3 per cent.; average of the three = 31·9 per cent.; "unknown finger" test—spot "1" = 21·9 per cent.; spot "2" = 27·1 per cent.; spot "3" = 35·1 per cent.; average of the three = 28·1 per cent.

When the averages for the three spots in each record of the "unknown finger" test are compared with the averages for all three spots on each finger and on all the fingers together in the ordinary test (in which the stimuli were restricted at any one time to a single finger) it is again seen that the average in the "unknown finger" test is considerably less than the average for all the fingers in the ordinary test. [Except in the case of record "10," which we may perhaps eliminate.] On the other hand, the average error of localization in the "unknown finger" test is more near to that of the best finger in the ordinary test. Usually it is somewhat greater than the average of the best finger in the ordinary test. Except upon one occasion (record "10"—which we may eliminate) the finger upon which tactile stimuli are most accurately localized is now the trained finger—the palmar aspect of the right index finger.

It would look as if the effect of the training of the right index finger extended to the localization of the spots—irrespective of the finger upon which they are localized—in the unrestricted "unknown finger" test. Table XXXII brings out this point. In that table there is first given the average for each individual spot in the five ordinary test records, and the average of the three averages; alongside these are given the corresponding averages for these spots in the "unknown finger" test—no account being taken of the correctness or incorrectness of the localization of the fingers. The extremely close approximation of the two sets of figures will be observed. On the whole those for the "unknown finger" test are slightly greater—that is, the errors of localization are slightly greater—than for the right index finger in the ordinary test, in which the stimuli were then restricted to that finger. In this case there was at times a fairly close approximation between the individual percentage errors of the three spots on the right index finger in the ordinary tests on the separate days and the errors for three spots (irrespective of finger) in the "unknown finger" tests on the same days.

This was seen, for instance, in record "13," where 200 observations were made, about 67 stimuli being applied to each of the three spots (irrespective of the fingers—i.e., about 17 to each individual spot on each finger. On that day the errors per cent. for the individual spots on the right index finger in the ordinary test were: Spot "1" = 0·0 per cent.; spot "2" = 26·6 per cent.; spot "3" = 43·9 per cent.; average of the three = 23·5 per cent. Whereas the errors in the "unknown finger" test were: Spot "1" = 23·7 per cent.; spot "2" = 25·7 per cent.; spot "3" = 50·7 per cent.; average for the three = 33·4 per cent.

Now the inference from this would seem again to be that the effect of training the "place" element in the localization of tactile stimuli upon the right index finger was extended to the corresponding spots in the unrestricted "unknown finger" tests. Is the "finger" element in that localization also improved by the training?

TABLE XXXI.—This Table is similar to Table XXIX, but the Figures now are those obtained on the Five Days which immediately followed the Training of the Right Index Finger.

	Day of Experiment					
Finger	9	10	11	12	13	Average
R 2	**42·9**	**85·7**	**71·4**	**80·0**	**83·7**	= **72·7**
R 3	40·0	40·0	60·0	33·3	44·4	= 43·5
R 4	80·0	80·0	40·0	57·1	73·5	= 66·1
R 5	50·0	75·0	50·0	71·4	65·4	= 62·4

Apparently not. In Table XXXI the figures for the errors of localization of the different fingers (irrespective of the place of the spots upon them) are given. On comparison with Table XXIX (before training the right index finger, or rather, partly also after the commencement of that training) it will be seen that now the trained right index finger is definitely less accurately localized than before the training. It indeed is now the least accurately localized finger, and the error of localizing it is not markedly less than the error of hazard. The localization of the third digit is also worse than before the training; while the fourth and fifth digits are more accurately localized than before. The figures for record "13" are peculiarly valuable, as they are obtained from a large series of observations—200, about 50 stimuli applied to each finger. The percentage error of the localization of the trained right index finger is here definitely and markedly above the error of hazard. The error of hazard is about 75 per cent.; the error of localizing the right index finger is 83·7 per cent. This points quite distinctly to the presence of "positive error"—to a definite distortion of the "finger"

element in the localization of spots on the right index finger. And this even where the error of localizing these spots on that finger when the experiment is restricted to it has markedly fallen after the training.

TABLE XXXII.—This Compares the Average Error per cent. of Localization of Tactile Stimuli on each Individual Spot of the Trained Right Index-finger in the Five Records taken after the Training, along with the Average of the Three Averages. Beside them is placed the Average Errors of the Three Spots in Four of the Five Records of the "Unknown Finger" Test taken on the same days (Record "10" being left out). These Errors are Irrespective of the Error of Placing the Spot upon the Finger in this Test.

	Ordinary Test	"Unknown Finger" Test
	Records 9—13	Records 9, 11, 12, 13
Spot 1 ..	0·00 ..	5·9
2 ..	20·99 ..	21·4
3 ..	26·53 ..	25·2
Average ..	15·8 ..	17·5

There can, we think, be little doubt that in some manner the training of the spots on the palmar aspect of the right index finger has resulted in a general improvement in the localizing of the place of tactile stimuli applied to these spots irrespective of the finger upon which they are localized in the unrestricted "unknown finger" test; but that there is absolutely no improvement in the localizing of tactile stimuli upon the trained finger in that test. As it were, there may well be two elements in the "position" of the stimulus applied to a spot—its location upon a certain and perhaps rather indefinitely bounded portion of the body, and its more exact location within that region. These two elements seem to be independent to this extent, that one may show marked improvement in cases of this sort and after training specially directed to that improvement, while the other may exhibit no such improvement. Where the improvement of one element in "position" occurs it seems to be extended to other similar elements in other similar spots.

(7) *On the Question of the Nature of the (apparent) general Improvement of Localization of Tactile Stimuli which occurred in the untrained Fingers.*

In the preceding subsections of this part of the paper we have noticed that there was an apparent general improvement of localization of tactile stimuli on all the fingers—trained and untrained—in the five

days of the experiment which followed the first period of training. This improvement is seen when we examine the averages for each set of spots, and it might perhaps be inferred that in some way it also was conditioned by the training of the set of spots on the palmar aspect of the right index finger. But we have already pointed out that an examination of the incidences of error for each spot on each finger seems to throw doubt upon the accuracy of such an inference, for the general improvement in the untrained fingers is not conditioned by an increase in the accuracy of localization for the spots which correspond to those which exhibit the greatest improvement upon the trained finger.

Another possibility is that this general improvement on the untrained fingers may be due to practice; while a third (perhaps associated with the second) is that the apparent general improvement is conditioned by the disappearance of the "confusion" error.

In the earlier records of this series the subject repeatedly indicated that he was unable to make a localization, although he was aware that a tactile stimulus had been applied. It happened that, after the period of training of the palmar set of spots on the right index finger, this error practically disappeared from the records. When it occurred we counted it as a wrong localization; but it is clear that, if the subject had made an attempt to localize these stimuli, a certain proportion of them might have been correctly localized. This would have been the case even if the subject had guessed these localizations, for then one-third of them on an average would have fallen upon the correct spot.

But if a certain proportion of a number of answers which in one period of the experiment is counted as definitely wrong, is in a later period of the experiment to be counted as definitely correct, it is clear that an apparent increase in the accuracy of localization may occur. Is the disappearance of the "confusion" error the condition of the apparent general improvement of localization in the untrained fingers?

It is not easy to decide how to treat this phenomenon of the disappearance of confusion. Thus the subject was unable to localize a certain proportion of the stimuli before the period of training. But after that period he was apparently able to localize nearly all the stimuli which were applied to him. We may say that he apparently became able to localize that proportion of stimuli which previously he could not localize.

But *how* did he localize them? There are here many possibilities. Thus he may have localized this proportion of stimuli purely by hazard,

or he may have localized it all on a certain specific spot (that spot being the same one on each finger, or varying on the different fingers); or he may have localized it always on the correct spot (for the "confusion" error occurred when the stimulus was applied to any of the three spots on a finger; or he may have localized it always on incorrect spots; and so on. Finally, he may have localized this proportion of stimuli in the same ratios as between the definitely correctly localized stimuli and the definitely incorrectly localized stimuli at the time when the confusion error was present.

We may, perhaps, regard the "confusion" answer as in some manner conditioned by a stimulus the localization factor of which is subliminal; and the disappearance of the confusion error as conditioned by a fall in the localization threshold. If we accept such a view we would be predisposed to think that the previously "confused" proportion of answers would be localized in the same proportions as those which previously were definitely localized as between right and wrong. The cerebral mechanism is in some manner disturbed by the lesion, and when a stimulus can be localized certain definite errors occur. It would be expected that these same errors would be seen in the proportion of "confused" answers if they became definitely localized ones.

An interesting result is obtained if we analyse the figures for the localizations in each set of spots before and after the period of training, and endeavour to correct for the disappearance of the "confusion" error (Table XXXIII). Thus in the records before the training of the palmar set of spots of the right index finger there was: (1) a certain proportion of indefinite localizations (that is, the "confusion" answers); (2) a certain proportion of definite localizations which were correct, and (3) a certain proportion of definite localizations which were wrong. After the period of training "1" practically disappeared. Now if we take "1" and divide it in the proportions of "2" and "3" (that is, in the ratio of the correct to the incorrect answers) and take that proportion which corresponds to "3" and add it to "3," we obtain a correction of the confusion error and the resultant will be the proportion of definite wrong localizations which would be expected to be made if there was no "confusion." This has been done in Table XXXIII, and it will be seen that the computed figure for definite incorrect localization agrees very closely with the actual figure for incorrect localizations obtained in the records after the period of training and when the "confusion" answer had disappeared. But it does so

only in the case of the untrained fingers. The actual figure in the case of the trained right index finger is very much smaller than the computed.

TABLE XXXIII.—Table showing the possible Effect of Disappearance of the "Confusion" Error. Except those in Column "G," the Figures refer to the Experiments before the Training of the Right Index Finger. They are given for each Aspect of each Finger, and for the Three Individual Spots of the Palmar Set on the Right Index Finger. Column "A" gives the Percentage of Correct Localizations; Column "B," the Percentage of "Confusion" Answers; Column "C," the Percentage of Definitely Wrong Localizations; Column "D" gives the Percentage of Definite Localizations (Right and Wrong); Column "E" gives the Percentage of "Confused" Answers which would have been expected to be Wrong if the Proportion of Answers in Column "B" had been divided as between Definitely Right and Definitely Wrong in the same proportions as those in Columns "A" and "C"; in Column "F" the Figures are obtained by adding those in Columns "C" and "E" together—thus giving the Total Percentage of Definitely Incorrect Localizations if the "Confusion" Answers were Eliminated; and in Column "G" the actual Figure for Percentage Error obtained after the Training of the Right Index Finger (when "Confusion" disappeared) is given for comparison.

Finger		A	B	C	D	E	F	G
Palmar	**R 2**	**57·30**	**14·37**	**28·33**	**85·63**	**4·75**	**33·08**	**15·72**
	R 3	68·02	7·37	24·61	92·63	1·96	26·57	29·68
	R 4	53·28	10·20	36·52	89·80	4·15	40·67	43·06
	R 5	56·94	7·61	35·45	92·39	2·92	38·37	40·68
Dorsal	R 2	71·44	11·79	16·77	88·21	2·24	19·01	21·62
	R 3	81·24	5·50	13·26	94·50	0·77	14·03	15·72
	R 4	73·20	9·18	17·62	90·82	1·78	19·40	20·62
	R 5	67·38	12·49	20·13	87·51	2·86	22·99	22·16
R 2 Spot	"1"	67·57	8·11	24·33	91·90	2·14	26·47	0·00
	"2"	37·50	25·00	37·50	75·00	12·50	50·00	20·98
	"3"	65·00	10·00	25·00	90·00	2·78	27·78	26·53

This would seem to show that the apparent general improvement of localization of tactile stimuli in the case of the untrained fingers is actually referable to the disappearance of confusion—which synchronized with the period of training; but at the same time it shows definitely that the improvement of localization in the case of the trained finger is not referable to this, and it strongly emphasizes our suggestion that this was indeed conditioned by the training.

The same table gives information with regard to the three individual spots on the palmar aspect of the right index finger. Of these, spots "1" and "2" showed a very definite improvement in localization while spot "3" showed a much smaller improvement. When the "confusion" error before the training is corrected in the manner described above, it is found that in the cases of spots "1" and "2" the computed

figure is very much greater than the figure for the definite incorrect answers after the period of training. But the computed figure for spot "3" is only slightly less than the actual one. This seems to show that the effect of the training was to increase the accuracy of localizing stimuli which were applied to spots "1" and "2," but not to increase it for stimuli applied to spot "3"—or to increase it very slightly for that spot.

If we assume that the proportion of previously "confused" answers was definitely localized by hazard after the disappearance of the confusion—instead of being definitely localized in the same ratio as the definitely localized answers (correct and incorrect)—there is again a fairly close correspondence between the computed figures and the actual figures for definitely localized answers after the disappearance of the "confusion" phenomenon. These figures are given for the percentages of definitely localized incorrect answers in Table XXXIV—where they are compared with the figures computed in the manner described before. In each case the difference between the computed and the actual figure is given.

TABLE XXXIV.—In this Table Columns "F" and "G" are the same as the correspondingly marked columns in Table XXXIII. Column "H" gives the Difference between the Two, "+" signifying that the Real Figure (i.e., that in Column "G") is greater than the computed. In Column "I" the Figure is computed on the assumption that the previously "Confused" proportion of Answers was Localized by Hazard after the Disappearance of the Confusion—that is, that Two-thirds of this Proportion of the Answers was Incorrect. Column "K" is a repetition of Column "G"; and Column "L" gives the Difference between the Numbers in Columns "I" and "K."

Finger	F	G	H	I	K	L
Palmar R 2	33·08	15·72	−17·36	37·91	15·72	−22·19
R 3	26·57	29·68	+ 3·11	29·52	29·68	+ 0·16
R 4	40·67	43·06	+ 2·39	43·32	43·06	− 0·26
R 5	38·37	40·68	+ 2·31	40·52	40·68	+ 0·16
Dorsal R 2	19·01	21·62	+ 2·61	24·63	21·62	− 3·01
R 3	14·03	15·72	+ 1·69	16·92	15·72	− 1·20
R 4	19·40	20·62	+ 1·22	23·74	20·62	− 3·12
R 5	22·99	22·16	− 0·83	28·46	22·16	− 6·30
R. 2, Spot "1"	26·47	0·00	−26·47	29·47	0·00	−29·47
"2"	50·00	20·98	−29·02	54·17	20·98	−33·19
"3"	27·78	26·53	− 1·25	31·67	26·53	− 5·14

It will be seen that the computed figure is still larger than the actual one in the case of the trained finger; as well as in the case of the two individual spots which showed the greatest improvement in that finger. In the case of the percentage errors of localization for the palmar aspects of the untrained fingers a very exact correspondence

between the computed and the actual figures occurs. But there is a less close correspondence when the figures for the dorsal aspects of the fingers are examined. There in every case the computed figure is greater than the actual one.

It would, therefore, appear that the improvement in accuracy of localization of stimuli applied to the trained palmar set of spots (or to two of these three spots when the figures are analysed more closely) cannot be ascribed to the disappearance of the "confusion" error which synchronized with the period of training. The apparent slight general improvement in localization seen in the palmar sets of spots of the three untrained fingers may be explained as due to the disappearance of the confusion error, whichever of the two manners of correcting for that error we use; but, if it be corrected for on the assumption that the previously unlocalized proportion of answers becomes localized in the same ratios (as between definitely right and definitely wrong) that obtain in the previously definitely localized answers, it would appear that instead of an apparent slight general improvement of accuracy of localization after the training there is a slight actual deterioration. In the case of the dorsal sets of spots, if the correction is made as above there would also appear to be a slight actual deterioration; but if the correction is made on the assumption that the previously unlocalized proportion of answers was localized by hazard, there would appear to be a greater actual improvement of accuracy of localization.

There is less variation in the results if the correction is made in the first manner than if it is made in the second, and we think that we are probably justified in the assumption that, at this stage in the experiment, the general improvement in accuracy of localization of the untrained sets of spots was an apparent one only, and conditioned by the disappearance of the "confusion" error.

VI.—Clinical Description of the Case.

Family history.—J. H. L., the patient, is the eldest son in a family of three. He was born in 1886. Both parents are alive and healthy. There is no history of nervous disorder in the family.

Previous history.—The patient left school at the age of twelve, having reached Standard IV. For some years he worked on a farm with his father who was a brewer's maltster. At the age of 23 he joined the Army, and served from March, 1909, to March, 1912. On leaving the Army he worked as a platelayer on the railway.

On the outbreak of war he was called up, and went abroad with the 1st British Expeditionary Force.

With the exception of influenza in 1910 he had no illness of any description.

History of present illness.—The patient was wounded near Ypres on October 26, 1914, about 2.30 p.m. His company was in the trenches repelling a German attack. He was in a leaning attitude firing as rapidly as he could. While in the act of pressing the trigger he felt a sudden shock in his head, and lost consciousness for about five minutes. When he recovered he found himself in a sitting posture. He could feel blood running over his face. He was blind and unable to understand what his comrades were saying. At the moment when he was knocked out he had been speaking, and he now found himself unable to utter any word except "Yes."

When the Royal Army Medical Corps orderlies gave him a drink of water he was given much more than he required, as he kept on repeating "Yes," "Yes." He had a vague idea that he was being captured by Germans and started to struggle. He found, however, that he was quite unable to use either limb on the right side.

He lay in the trench until nightfall and was then removed on a stretcher to the Medical Officer's dressing station. He was very weak from loss of blood.

He was conveyed by motor ambulance to Boulogne and on reaching hospital was taken straight to the operating theatre. On waking next morning he felt very weak and unable to move. His speech had not returned, but he could now understand what people were saying and could see.

During the first day in hospital he had a vivid dream of walking under the Eiffel Tower.

His speech and ability to read remained in abeyance for about a week, but long before he could speak he was able to sing songs which he knew by heart.

During the first few days of his illness he had incontinence of fæces, but no difficulty with regard to micturition. On the fourteenth day after admission the right side of his face twitched for a few seconds. One day he saw a magazine lying on the bed next to his own and for some hours he lay trying to puzzle out the title on the front page. Suddenly it came back to him, and he alarmed the ward by exclaiming "Bystander" in a loud voice. After this his vocabulary rapidly grew, but he stammered a great deal when speaking. All parts of speech came back with equal rapidity.

On December 15, 1914, he was shipped to Southampton and sent to a hospital in Wandsworth. At this time he was still paralysed on the right side. At the end of a month he was allowed to get up. He felt very weak and with assistance could only walk a few yards.

During his residence in this hospital he suffered considerably from his eyes. He had much photophobia, and felt dizzy when he looked at objects. For a fortnight he wore an eyeshade.

With regard to his paralysed limbs, recovery of power began in the lower extremity, and was much more rapid than in the upper limb. The right side of his face was also paralysed, and at first his tongue used to fall to one side, so that he bit it during sleep.

For many weeks he was quite unaware of the position of his affected limbs in bed, and had to grope for his right hand. Five weeks after admission to hospital in London he had a "seizure" affecting the right side. He had been gargling his throat with salt and water, and swallowed some the "wrong way." While in the act of coughing violently the muscles on the right side of his body began to twitch, producing irregular movements of the right upper and lower limbs. Consciousness was preserved, and in about five minutes the attack passed off.

This epileptiform seizure was followed by a change in his mental state. On the following day he developed the delusion that other patients were making disparaging remarks about him. He had several more seizures before leaving this hospital, and found that their duration was shortened if he remained quite motionless and silent.

While in bed his right lower extremity was habitually flexed at the knee. He made an effort to straighten it one day by pressing his foot against the bed-rail. He became suddenly giddy and appears to have lost consciousness, and to have remained in a stuporose state for several days. Recovery was followed by the appearance of fresh delusions. A magazine illustration of famous generals which he saw in the hospital library suggested to him that he must be Napoleon's grandson. This delusion was accompanied by auditory hallucinations. A voice repeatedly told him of his imperial rank.

His explanation of this delusion is worth recording. The date of publication of the magazine was that of his father's birthday. This occurred to him when he was looking at the photograph of the Kaiser and Napoleon, and it at once became clear to him that he must be Napoleon's grandson.

On March 1, 1915, he was transferred to the Royal Victoria Hospital, Netley. He had so far recovered that he was able to walk to the station. His memory for this period is good. He remembers giving particulars of himself and being put to bed. He became excited and repeatedly shouted "Three cheers for the Red, White and Blue." Every time he said this a "voice" echoed his words. At the end of three days he was transferred to the Military Hospital, Maghull. At the station he struggled and was put in the guard's van. He was seized with the idea that he was being electrocuted through the floor, as he had a sensation of pins and needles in his right lower limb, and involuntary movements on the same side. This delusion persisted for some weeks. Not only did he hear imaginary "voices" talking about electrocution, but a patient in the bed next his own talked a great deal about electricity. In this way he was encouraged in his false belief.

When examined on the day after admission he was found to be dull and lethargic. He expressed delusions of grandeur, and exhibited "negativism." He had difficulty in selecting words. Articulation was slow and slurring. Paresis of both extremities on the right side was noted. He showed coarse tremor, slight nystagmus, and increased deep reflexes. Ankle-clonus existed on the right side.

During the summer of 1915 his mental state underwent but little change.

His delusions persisted, and he was inclined to be aggressive. Motor power gradually returned in his affected limbs. He continued to have fits, and on three occasions lost consciousness; usually the fits were Jacksonian in type, and presented the following characteristics. A sudden sensation of vibration or electricity in the right arm, accompanied by a feeling of faintness, warned the patient to lie down. He remained conscious, could see and hear everything, but was unable to speak. Twitching of his muscles next occurred; the thumb was always first affected; then, in order. the hand, elbow, shoulder and body on the affected side. The leg was affected last, while the face always escaped. On several occasions the head was deflected to the right. Each fit was followed by transient motor weakness in the affected limbs, while articulation became more impaired for several days.

In the later months of 1915 his attacks became less frequent and his mental state improved greatly; he became tractable and lost his delusions. Auditory hallucinations persisted until the month of November.

The following notes on his condition were made during the last week of November, 1915.

Clinical examination.—The patient is a tall, well-developed man; he is right-handed. His pulse is irregular and intermittent. His urine contains no albumen and his radial arteries are not thickened. The wounds of entry and exit, which mark the course of the bullet which penetrated the patient's skull, lie in the following situations: The former lies 12 cm. posterior to the nasion and 5 cm. to the left of a line joining that point with the inion; the latter (wound of exit) measured along this sagittal line lies 29 cm. posterior to the inion, and 3 cm. to the left of the median plane. The area of each of these cranial wounds is equal to that of a sixpenny-piece. Immediately anterior to the wound of exit there is a large trephine opening in the parietal bone, in which pulsations can be observed. It has an antero-posterior length of 11 cm., and a breadth of 4 cm. Its anterior extremity lies 22 cm. posterior to the inion and 3 cm. to the left of the median plane. Pressure on the edges of this foramen causes intense local pain. He is observant and intelligent.

We take the opportunity of remarking here how much we are indebted to the patient himself for our subsequent experiments, which would hardly have been possible without his intelligent co-operation and patience. His memory and attention are good. He has no disturbance of perception. Articulation is slow and slightly impaired; he stumbles and hesitates when pronouncing certain words. He is able to read, and writes with his left hand. In carrying out simple orders he confuses the right side with the left. For example, when told to close his right eye he almost invariably closes his left. Occasionally he uses wrong words, and has difficulty in finding the word he wants. In the addition of figures he frequently makes mistakes. There is no apraxia. He states that when excited he becomes deaf in the left ear.

Special senses.—Smell, taste, and hearing are normal. The visual fields are restricted, especially that of the left eye.

Cranial nerves.—The pupils are equal and react normally to light and on

accommodation. Ophthalmoscopic examination reveals evidence of previous retinal change. The disc margins are slightly obscured and the vessels near the disc ill-defined. There is very slight motor weakness of the right side of the face; the right eye is habitually more open than the left. When he closes the right eye there is overaction of the facial muscles on the same side. The corneal reflexes are equal. The functions of other cranial nerves are normal.

Motor system.—The left limbs are unaffected. The size of the muscles is equal in the two upper limbs, but their tone is much increased on the right side. There is slight contracture of the fingers. The range of movement is normal at the right shoulder, elbow and wrist joints, but movements of the thumb and individual fingers are much restricted. The right upper limb is much weaker than the left; the grasp of the right hand, measured with the dynamometer, is only 23 kgm., while on the normal side it is 45 kgm. Voluntary power is especially weak in the interossei and in the intrinsic muscles of the thumb. Movements of extension of the digits are much weaker than those of flexion. Adduction of the thumb is very imperfectly performed, and a movement of flexion of the thumb accompanies flexion of any of the fingers. The thumb is usually flexed at the metacarpophalangeal joint, adducted, and extended at the interphalangeal joint. Loss of voluntary movement is more complete in the fifth digit than in the index finger. Full extension or flexion of the little finger is impossible, and the attempt is accompanied by movements of other fingers. Owing partly to this motor weakness and partly to the co-existent ataxia, the limb is only used for general movements at the large joints, and is useless for finer actions. The patient holds his pipe, writes, dresses himself, &c., with the left limb.

The right upper limb is often colder than the left and slightly cyanosed.

Abrupt irregular involuntary movements may frequently be observed in the thumb and fingers. These take the form of a sudden flexion at the basal joints of one or more fingers, or an isolated movement of the thumb. They are sometimes entirely absent for several days, and are most noticeable before seizures.

The patient is unaware of their occurrence unless his attention is specially directed to his affected limb. The patient has himself observed that these involuntary movements can be increased by making strong volitional movements of the normal limbs or of the right foot; he has further observed that he can restrain them by concentrating his attention on his hand. Thus, for example, strong voluntary movements of the toes of either foot may produce involuntary movements of the affected fingers, and if, while continuing these voluntary movements, the patient directs his attention to his hand, he may succeed in arresting or diminishing the involuntary movements of the fingers. The act of yawning is accompanied by flexion of the thumb and fingers and of the wrist of the right upper limb. All movements of the right upper extremity are very ataxic. When the patient extends both upper limbs horizontally in front of him, the right arm performs swaying movements as soon as the eyes are closed.

There is no wasting of the right lower limb; the tone of its muscles is increased. There are no contractures and the range of movement is unrestricted. There is slight motor weakness in the affected limb. There are no involuntary movements. Marked ataxia exists and is well seen when the patient performs the heel to knee test.

Gait: In walking the right upper arm is adducted and remains rigidly applied to the side; movement takes place at the elbow, the forearm swinging loosely. The right lower limb executes a slight movement of circumduction at the hip. In descending or ascending stairs it is raised higher than necessary, and is then planted in an uncertain manner. The right shoulder droops perceptibly.

Reflexes.—The right arm-jerks are exaggerated; the knee- and ankle-jerks are exaggerated. Those on the right side are brisker than on the left. Ankle-clonus cannot be obtained. The plantar reflex is usually absent on the right side, on the left a normal flexor response is obtained. After a Jackonian fit, however, an extensor response exists for some hours on the right side. The abdominal reflexes are equal on the two sides.

Subjective sensations.—He has frequent headaches on the left side of the head, and local pain in the neighbourhood of the cranial wound. In his right upper limb he has often a feeling of numbness, and sometimes there is a feeling as though the whole of the right side did not exist. The knowledge of position of his right upper limb is very imperfect when he is without the guidance of vision.

Tactile sensibility.—He cannot appreciate cotton wool touches with certainty on the tips of the fingers of the right hand, nor on their dorsal surfaces. On these areas his answers are irregular, and he often entirely fails to appreciate the stimulus. Elsewhere on the right upper limb cotton wool touches are recognized, but there is a subjective difference; the feeling is "weaker" on the right side and "not so tickly" as on the normal side. The same difference is felt on the right malar region, and on the right ear there is a "vast difference." On the right side of the abdomen and on the right lower extremity, a wisp of cotton wool rubbed across the skin seems less distinct than on the left side. He is unable to define exactly this feeling, and states that on hair-clad parts the cotton wool produces a "creeping sensation," which is diffuse, being felt over a wide area of the leg. For the purpose of examining with graduated tactile stimuli, hairs mounted on matches were roughly calibrated by measuring on a balance (in grains)[1] the force exerted by them in bending. A series of nine hairs exerting pressures varying from ½ to 140 gr. was obtained, The method of applying the graduated tactile stimuli was that adopted by Head and Holmes. A hair is selected producing a stimulus just above the minimum threshold to which the normal hand reacts with constancy when the stimulus is applied sixteen times in the minute; the same hair is used in the same manner to a corresponding part of the affected hand, and then more powerful hairs are used, up to those exerting many times the pressure.

[1] Metric system weights were unobtainable in this hospital.

The strength of the stimulus is then decreased to the hair with which the testing was begun, ending up with a series of contacts on the normal hand.

The following result was obtained when hairs of various bending strains were applied sixteen times in the minute to an area of skin on the dorsal aspect of the hands (between the third and fourth metacarpal bones).

A stroke represents a correct answer; a nought, that the patient did not respond; a broken stroke represents an hallucination.

Hairs (bending strain in grains)	Normal hand (left)	Affected hand (right)
7	1111111111111111	—
7	—	0110000000100000
12	—	0001011111110111
20	—	1111111111111010
30	—	1111111110111011
40	—	1111111110011011
80	—	1111011111111111
40	—	0111111010111100
30	—	1111111011111100
20	—	0001111100100011
12	—	0000100111010010
7	—	0100001010000000
7	1111111111111111	—

Thus it is apparent that on the normal hand a perfect series of answers can be obtained with a hair of 7 gr. bending strain, but on the affected hand the answers are slower (the patient remarking, "It don't send the message to the brain quite so soon") and inconstant. There is a persistence of sensation, and hallucinations occur. No definite threshold is obtained. On the flexor surface of the right forearm the answers are still irregular, and are much disturbed by hallucinations and persistence of sensation. On the upper arm (bicipital area) evidence of a definite threshold is obtained, and there are no hallucinations. On the face a threshold can be obtained with hair "3." The record is not disturbed by hallucinations, and there is no slowness in response. The sensation evoked by the hair is not quite similar on the two sides. On the sole of the foot it is possible to obtain evidence of a definite threshold; hallucinations, however, are numerous. On the dorsal surface of the foot, on the inner aspect of the leg, and on the right side of the abdomen (umbilical level) the answers continue to be slow, irregular, and disturbed by hallucinations.

The following record illustrates the condition.

Abdomen (Umbilical Level).

Hairs	Normal side (left)	Affected side (right)
3	1111111111111111	—
3	—	1111111111111111
8	—	1111011111111111
30	—	1111111111111111
40	—	1111111101111111
70	—	1111011111111111
90	—	1111111111101111
70	—	1111111111110001
40	—	1101110011111111
30	—	1101111101111111
8	—	1110010100101111
3	—	1001110110010100
3	1111111111111111	—

Pressure touch.—Tested roughly with the pulp of the observer's finger or by a blunt-pointed rod (whose movement through a cylinder is resisted by a rubber band), showed an uncertainty of response, and a tendency to evoke hallucinations on the right hand and forearm. Pressure touch on the right side of the body does not always evoke the same sensation as on the left. Thus, pressure with the blunt end of a pencil on the right cheek, or on the right side of the abdomen, evokes a sensation as though a much broader object were being applied. There is a feeling of "spread-outness" which is not experienced on the normal side.

Roughness.—The same thresholds are obtained on both sides with Graham Brown's æsthesiometer. With sand-paper, four grades of roughness can be readily identified. The relative roughness of any two grades can also be distinguished. No difference can be detected between the two sides.

Tickling and scraping.—No difference to tickling or scraping can be detected between the palms or the soles of the feet.

Sensibility to pain. (*a*) *Superficial pain.*—When tested with a needle on the right cheek and on the right forearm, the patient states that the prick is less sharp than on the normal side, but the pain evoked is as great. On the right upper arm there is slight hyperæsthesia to pinprick. On other areas no difference can be detected.

(*b*) *Pressure pain.*—No difference between the two sides can be obtained. Measured prick was not employed.

Vibration.—On the right side the vibrations of a heavy tuning-fork (C) evoke sensations which are "not so plain" as on the normal side. The vibrations are appreciated for a shorter period on the right upper limb than on the left. Thus, when the patient can no longer appreciate the vibration on the right radial styloid process, it can be recognized for a period of seventeen seconds on the corresponding point on the left side. After the tuning-fork can no longer be appreciated on the left styloid process it is recognizable on the right side for a period of twelve seconds. There is thus a difference of five seconds between the two sides; and on the back of the hand it is much greater. No difference between the two sides can be obtained on the upper arm or on the lower limb.

Temperature.—The paretic limb is frequently colder than the left, but when this condition is not noticeable, definite changes in the response to thermal stimuli can be demonstrated. Thus, on the normal left palm the neutral zone lies between 27° C. and 31° C. On the right palm all temperatures between 26° C. and 37° C. appear to be neither hot nor cold. The power of comparing thermal stimuli is also defective. On the right side temperatures of 41° C. and 47° C. are correctly appreciated as hot, but he is quite unable to say which is the hotter. Similarly, he cannot discriminate between water at 15° C. and water at 20° C., whereas on the normal side he can always tell which of the two is the colder. Further, his answers on the right side are slow and irregular. On the sole of the right foot the neutral zone lies between 23° C. and 25° C.; on the normal foot it lies between 28° C. and 30° C. Here

again, however, his ability to discriminate the relative warmth of two tubes is diminished.

The application of a heat stimulus sometimes evokes a burning or slightly painful sensation on the right foot, when on the left side it is quite comfortable. On the same area a cold stimulus is described as feeling "all over the place," whereas on the normal side it is localized to one area. He has noticed while washing that water which is only sufficiently hot to be quite comfortable on the normal hand may cause a "stinging pain" on the right hand, which persists for several minutes after withdrawal.

Sense of position. (*a*) *Recognition of posture.*—The patient's recognition of the posture of his right upper limb is grossly defective. If the defect is measured by the method introduced by Horsley, and modified by Head and Holmes, the records obtained when the affected hand seeks the normal forefinger are very much better than when the patient attempts to point to the affected forefinger with his normal hand.

The examination of separate segments of the limb (by asking the patient to imitate, as exactly as possible with his normal limb, the posture of the affected part) shows that a grave loss is present, which is most profound in the distal segments of the limb. When one of the fingers or the thumb is placed in a particular attitude while the patient's attention is diverted, he is quite unable a moment later to imitate successfully the posture with his normal digits.

With regard to movements of the hand, at the wrist-joint he is less inaccurate, but confuses an attitude of flexion with one of extension. He does not imitate with the normal forearm attitudes of supination and pronation. The upper arm also shares in the defect, but in a much less marked degree. Recognition of posture is also impaired in the lower limb.

(*b*) *Rocognition of passive movement.*—The appreciation of passive movements is very much impaired. Movements are appreciated long before their direction can be recognized. Indeed, he is quite unable to recognize the direction of movement in the thumb or in any finger, unless hyperextension or very flull flexion is carried out. All the digits can be moved through a wide angle before the movement is perceived. At the wrist extreme flexion or extension only can be recognized, and movements through a very wide angle cannot be appreciated. Recognition of the direction of the movements of pronation and supination is grossly defective.

At the elbow-joint the direction of movement is usually correctly appreciated, when the angle of movement exceeds 60°.

At the shoulder-joint these defects are much less obvious. The recognition of passive movement and the direction of movement is also very defective in the toes and ankle. The occurrence of numerous hallucinations of movement can be noted at all limb joints, except those of the shoulder and elbow.

Localization, as tested by the modified Henri method, is found to be much affected on the right hand and forearm; and, to a lesser degree, on the right upper arm, right side of the face, and right lower extremity. Occasionally (on the right side) the patient states that he has no knowledge of the locality

of the contact, but in the majority of instances he localizes the stimulus in some false direction. This holds good, not only for the proximal segments of the limb, but also for the right fingers and palm.

For testing the patient's power of recognizing the position of a spot stimulated the pressure-touch instrument was used, the touches being repeated until the patient could appreciate the contact.

The following record was obtained by making the contacts in an irregular order on the dorsal aspect of each digit :—

Digit Normal hand (left)	Correct	Localized proximal	Distal	Localized on wrong digit	"Don't know"
Thumb	10	0	0	0	0
Index finger	10	0	0	0	0
Middle ,,	7	1	1	1	0
Ring ,,	8	1	1	0	0
Little ,,	7	1	2	0	0

Abnormal hand (right)	Correct (or on same level)	Proximal	Distal	Wrong digit	"Don't know"
Thumb	1	2	1	6	0
Index finger	2	2	0	6	0
Middle ,,	2	3	0	5	0
Ring ,,	2	1	0	7	0
Little ,,	2	0	1	7	0

Thus on the normal (left) digits he correctly localizes 42 contacts out of 50; while on the abnormal (left) digits only 9 are correctly placed. On another occasion, out of 20 painful stimuli equally distributed on the terminal phalanges of the right digits only one was correctly localized, 5 were incorrectly localized on the base of the thumb, and in three cases the patient had no idea of the situation of the stimulus. The dorsum of the hand was selected for a comparison of the accuracy of localization of tactile stimuli with accuracy of localization of painful stimuli; 35 touch stimuli and (afterwards) 35 pain stimuli (pin prick) were given; 7 stimuli in each case being applied to the area of skin above each metacarpal bone. The stimuli were applied in an irregular order and the patient attempted to localize them in the usual manner upon the hand of a model.

In the following table the distances of the points wrongly indicated from the spots touched or pricked are recorded in centimetres (to the nearest whole centimetre)—"C" indicating that the stimulus is correctly localized :—

Tactile stimuli (dorsum of right hand).

Skin areas over	i	ii	iii	iv	v	vi	vii (stimuli
1st metacarpal	10	8	4	8	6	10	8
2nd ,,	6	6	3	2	5	C	2
3rd ,,	C	5	4	2	5	3	5
4th ,,	1	1	1	4	C	5	2
5th ,,	4	C	C	1	4	2	2

Painful stimuli (dorsum of right hand).

1st	1	3	2	2	1	6	1
2nd ,,	2	2	1	2	2	2	C
3rd ,,	2	2	C	C	C	2	C
4th ,,	2	1	1	C	1	C	1
5th ,,	1	3	2	3	C	3	2

On the normal (left) hand in only one instance did the error in localization exceed 2 cm.

It would appear from the above observations that erroneous localization is present, both where the stimulus is one of pressure-touch and where it is a prick, but that in the latter case the error is not so great as in the former.

On the terminal phalanges this difference is less obvious. Out of 50 touch stimuli 12 are correctly placed, while out of a similar number of prick stimuli 17 are correctly localized (in 11 instances he had no idea of the locality of the stimulus). The patient remarked, "A prick seems often to concentrate at the wrist."

On the right forearm the power of localization is plainly defective, but the defect is not so great as in the case of the hand of fingers. Out of 20 pressure-touch stimuli 10 are localized in false positions which vary from 5 to 14 cm. in distance from the spot touched. In no instance does the patient fail to make a localization.

On the right upper arm localization is also disturbed, but is more accurate than on the right forearm.

Comparison of the accuracy of localization on the two sides of the face demonstrates a slight disturbance of localization on the right cheek.

The power of recognizing the position of stimulated spots on the right foot is much impaired. Out of 50 tactile stimuli applied either to the great toe or to the little toe, the number of errors on the left side is 7 and on the right side 26. The defect is present, although in a lesser degree, in the case of the right leg.

Compass test.—The power of discriminating the two points of the compasses is gravely affected on the right upper limb.

On the palm the patient cannot recognize the "two-ness" of two points synchronously applied, even when the distance between them is 6 cm.; whereas, on the normal left palm, no error occurs when the points are 1·5 cm. apart.

On the right side no threshold can be obtained for the fingers, palm, nor for the dorsal surface of the hand; nor can a threshold be obtained for the right forearm (neither surface), right upper arm, right side of the face, right forehead. Neither can a true threshold be found for the right lower extremity, nor for the right side of the abdomen. The power to recognize the double nature of the compass points is also lost on the right hand, when the points are applied successively.

The following are some of the records obtained:—

		Normal (Left)		Abnormal (Right)	
Palm	..1·5 cm.	1: 11 111 1 11 11 2: 111 1 1 11 11 1	1·5 cm.	1: 11 1111X 11X1 2: X1X 1XX XX X1	
			4 cm.	1: X XX 1XX 1X 1 1 2: 1 1 111 11 1 1X	
			6 cm.	1: 1 11 111 111 X 2: X1XX 11X 1 1X	

	Normal (Left)		Abnormal (Right)	
Forearm (flexor surface)	5 cm.	1 : 111 11 1 111 1 2 : 11 1111 111 1	5 cm.	1 : 11 1 111 1111 2 : X X XX XXX XXX
			15 cm.	1 : 1 1X XXX X XX1 2 : X1X 1X 11 11 1
Upper arm ..	6 cm.	1 : 1 111 1 111 1 1 2 : 11 1 1 11 111 1	6 cm.	1 : 11 111 X 10 11 2 : X 11 111 XXX X
			10 cm.	1 : 111 1 X1X 1 X1 2 : 11X X11 11 11
Face (cheek) ..	2·5 cm.	1 : 111 11 1 11 11 2 : 1 111 11 11 11	3 cm.	1 : X11 X X XX X 1 1 2 : 1X1 1 1 1X 1X 1
			6 cm.	1 : 11 11X 11 11 1 2 : 11 11 XX1 11 1
Sole of foot ..	2·5 cm.	1 : 1 1 111 111 11 2 : 11 11 111 1 11	4 cm.	1 : X 1X XX 1XX X 1 2 : 1 11X XX 1 X1 X
			10 cm.	1 : 1 11 11X 11 11 2 : X1X 11 1X X 1 1
Dorsum of foot	4 cm.	1 : 11 1 11 111 11 2 : 11 111 111 1 1	5 cm.	1 : XX 1 1X1 XXX 1 2 : X111 1 1 XX 11
			10 cm.	1 : 1 11X 1X 1X1 1 2 : 111 11 1 11 XX
Leg (inner aspect)	6 cm.	1 : 1 111 11 11 11 2 : 11 1 11 111 1 1	8 cm.	1 : 1 11 111 1 11 1 2 : XX1 X XX X X XX
			15 cm.	1 : 111 X 1 111 11 2 : 1 X1 11 XX X XX
Pectoral region (3rd rib)	7 cm.	1 : 1 11 111 1 11 1 2 : 1 11 111 11 1 1	7 cm.	1 : 111 11 1 X 11X 2 : 1 11X X1 11 11
			15 cm.	1 : X 1XX 11 1 111 2 : 111 1 1 11 11 1

His replies are characterized by slowness, uncertainty, and irregularity. On some occasions, when twoness is recognized, he states that the points feel very close together—although actually they may be separated from one another by as much as 5 cm.

Power of recognizing weight.—On the normal hand his power of appreciating weight is quite acute, but on the right hand it is much impaired. With the hand completely supported he can easily distinguish, on the left (normal) side, between 4 oz. and 8 oz., and 16 oz. and 24 oz., but on the abnormal right hand he cannot.

The power of recognizing addition and subtraction of weight is also much impaired.

With unsupported hands, when a weight is placed in each hand and the patient is asked to " weigh " them by raising and lowering his hands, the errors are equally gross. He thus cannot distinguish with certainty between 1 lb. and 1½ lb.; nor between 1 lb. and 2 lb.

Appreciation of size.—The patient has completely lost the ability to recognize differences in size of objects placed upon his right palm, nor can he distingush between the head and the point of a pin when they are gently applied to the skin.

Appreciation of two-dimensional shape.—He is equally at fault when asked to recognize various shapes when they are placed in contact with the surface of the right palm; on the left normal palm he has no difficulty in distinguishing them.

Appreciation of three-dimensional form.—The patient is quite unable to recognize common objects placed in his right hand when his eyes are closed. These objects are at once recognized when placed in the left hand. Thus:—

Object	Reply—right hand	Reply—left hand
1. An ink-pot	"Something hard, solid and cold."	"An ink-pot" (immediately).
2. A large tuning-fork	"Something hard, light and cold."	"A tuning-fork."
3. A rolled-up handkerchief	"Something soft and tepid."	"A handkerchief."
4. Small nail-scissors	"Cannot describe it."	"Nail-scissors."
5. A penny	"Just a feeling in my hand."	"A penny."
6. A large pocket-knife	"Hard, that's all I can say."	"A knife."

Appreciation of texture.—In spite of his power of recognizing roughness or smoothness, he has great difficulty in appreciating texture with the right hand. The following record illustrates his condition:—

Material	Reply—right hand	Reply—left hand
1. Velvet	"Soft, like rubber."	"Velvet."
2. Silk	"Coarse calico."	"Silk."
3. Towel	"Ribbed surface"	"Coarse towelling."
4. Flannelette	"Like calico."	"Flannelette."
5. Satin	"Not quite satin."	"Satin."
6. Velvet (again)	"Piece of coarse substance."	"Velvet."

With his right hand he is quite unable to appreciate any difference between velvet and flannelette; with his left hand he can distinguish them without difficulty.

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